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Gomi et al.

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(54) **ROBOT**

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B25J 9/16 (2006.01)

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CPC **B25J 9/1651** (2013.01); **Y10S 901/09** (2013.01)

(58) **Field of Classification Search**
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USPC 318/568.11, 568.16, 568.22, 568.23;
700/245, 250, 252, 253, 254, 258
See application file for complete search history.

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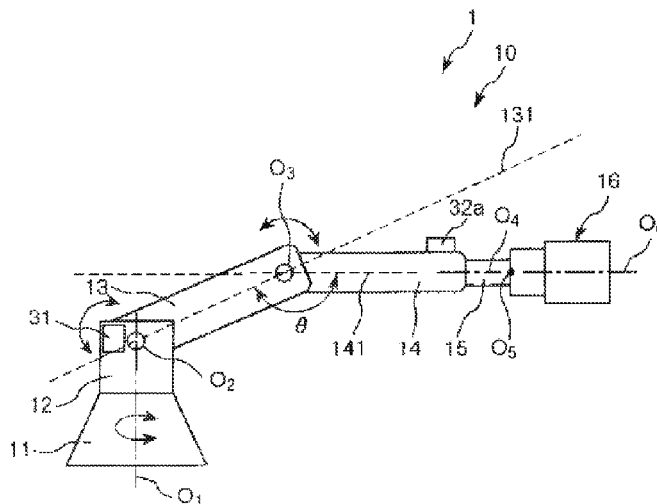
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(57) **ABSTRACT**

A robot includes a first arm that rotates around the first axis, a second arm that rotates around a second axis in a direction different from the first axis, a third arm that rotates around a third axis parallel to the second axis, a first inertia sensor that is installed at the first arm, a second (a) inertia sensor that is installed at the third arm, first to third angle sensors, a posture detection unit that detects the posture of the third arm with the second arm as a reference and derives a feedback gain, and a second drive source control unit that feeds back a second correction component, which is obtained by multiplying a value, which is obtained by subtracting the angular velocity ω_{A2m} and the angular velocity ω_{A3m} from the angular velocity ω_{A3} , by the feedback gain, and controls the second drive source.

9 Claims, 16 Drawing Sheets



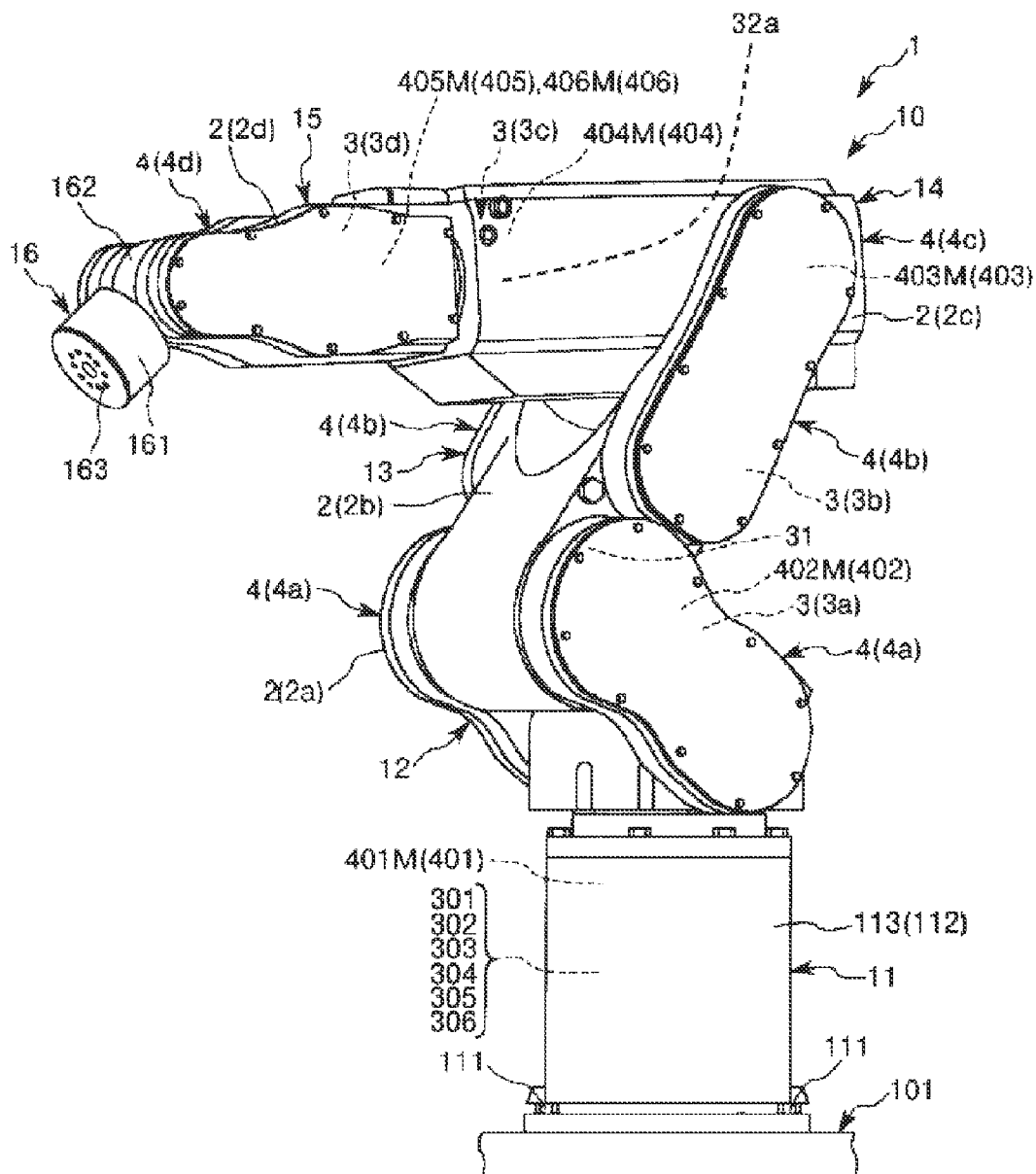


FIG. 1

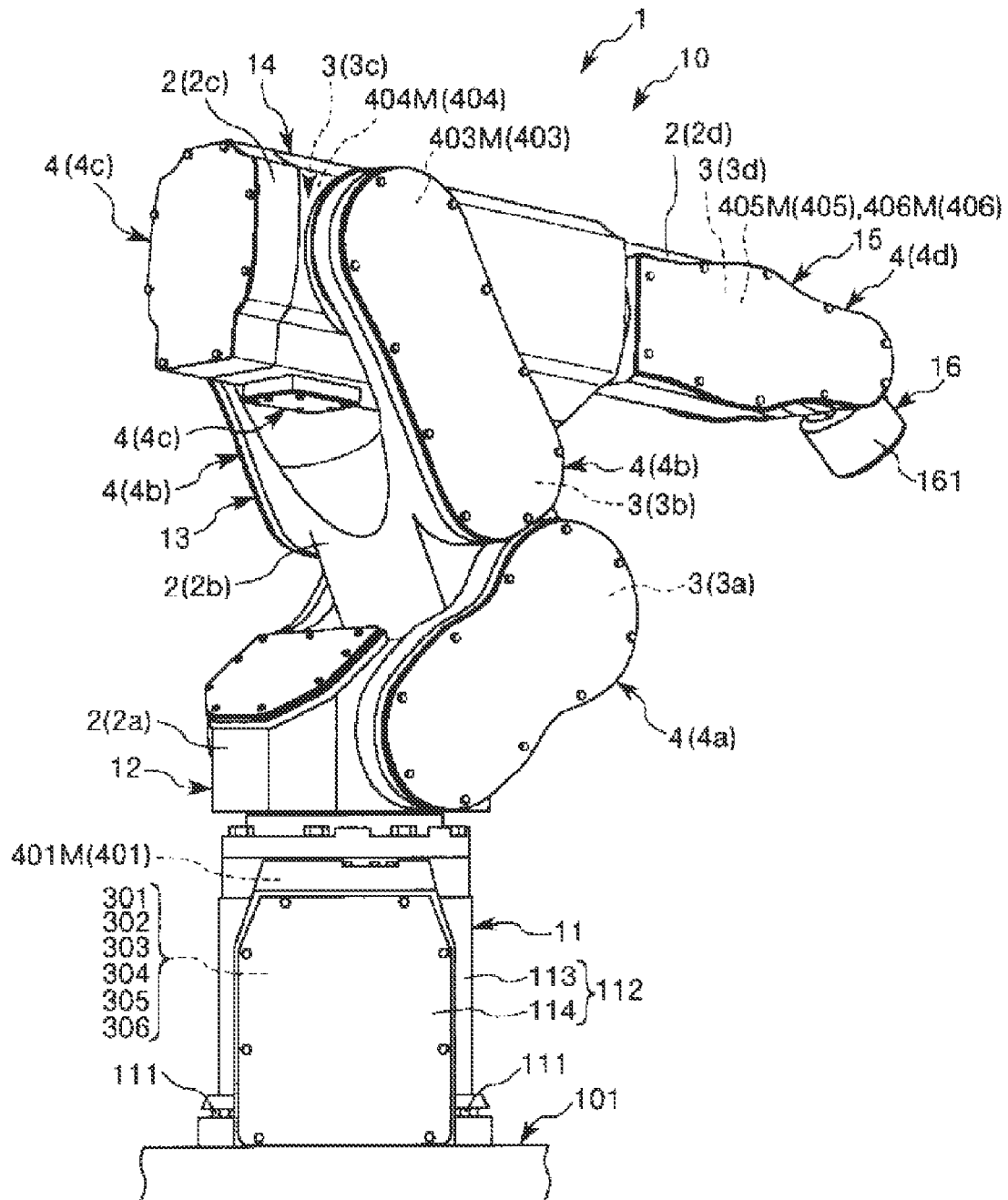


FIG. 2

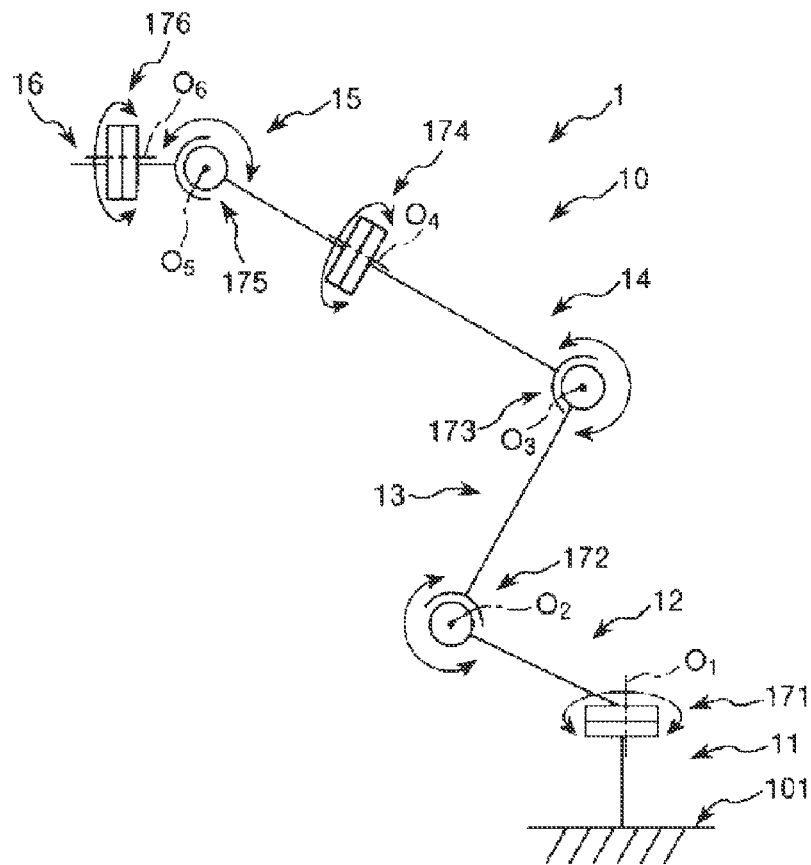


FIG. 3

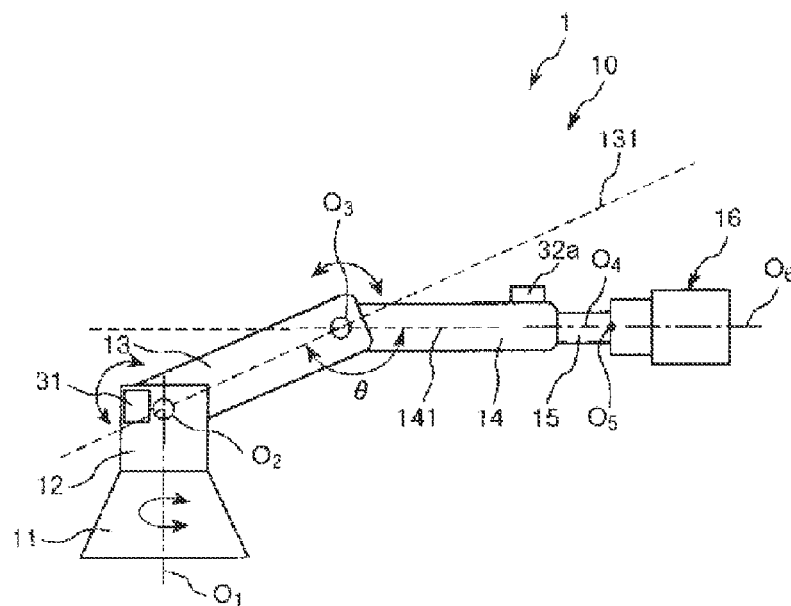


FIG. 4

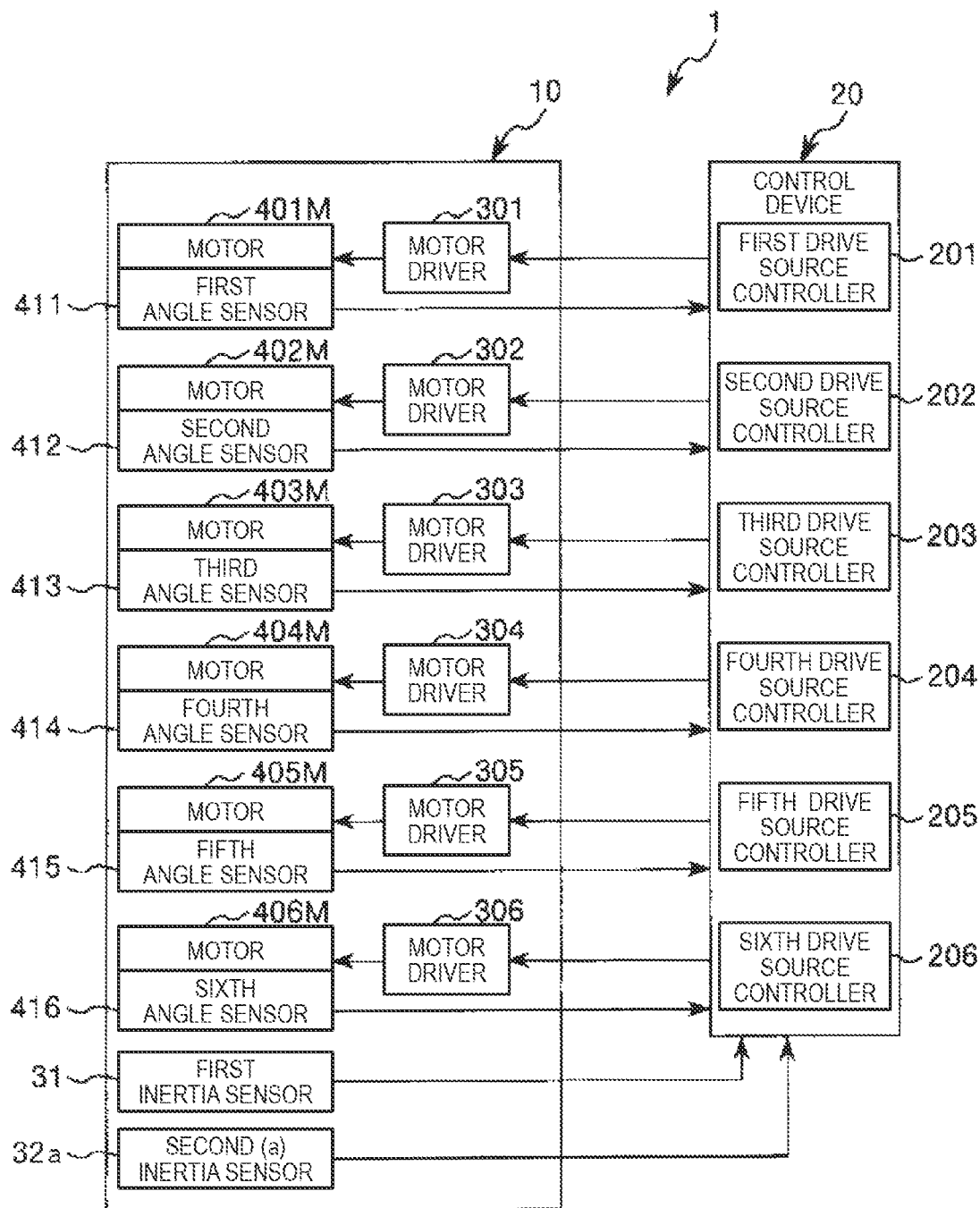


FIG. 5

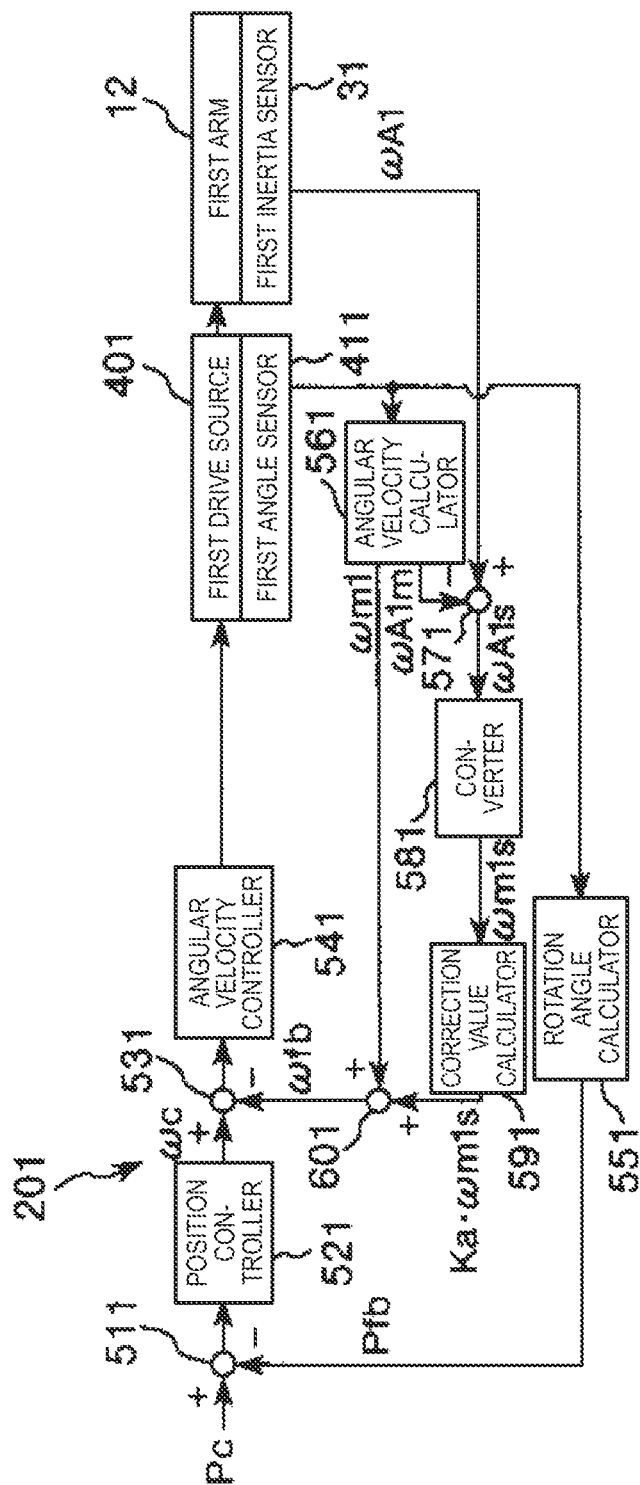


FIG. 6

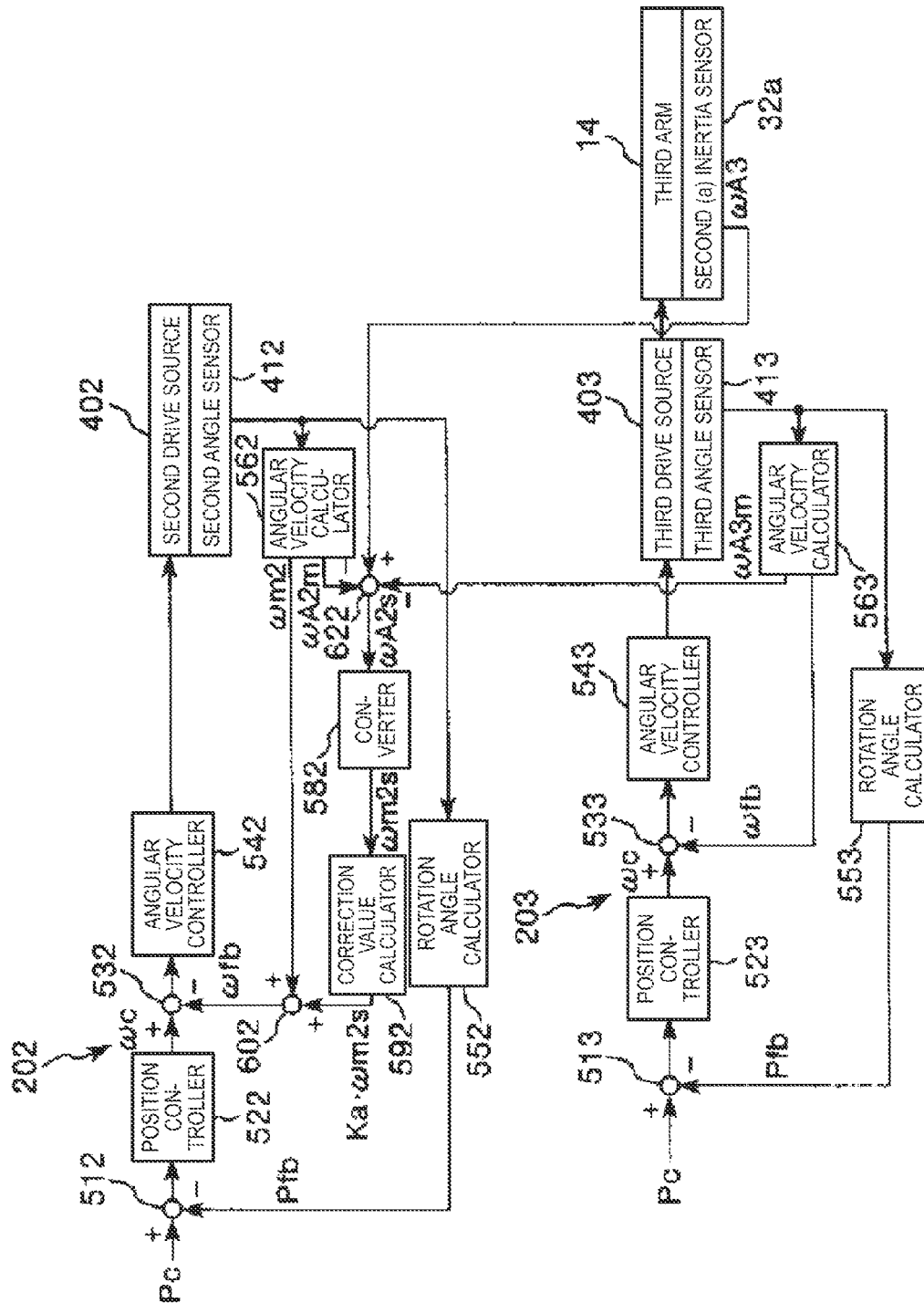


FIG. 7

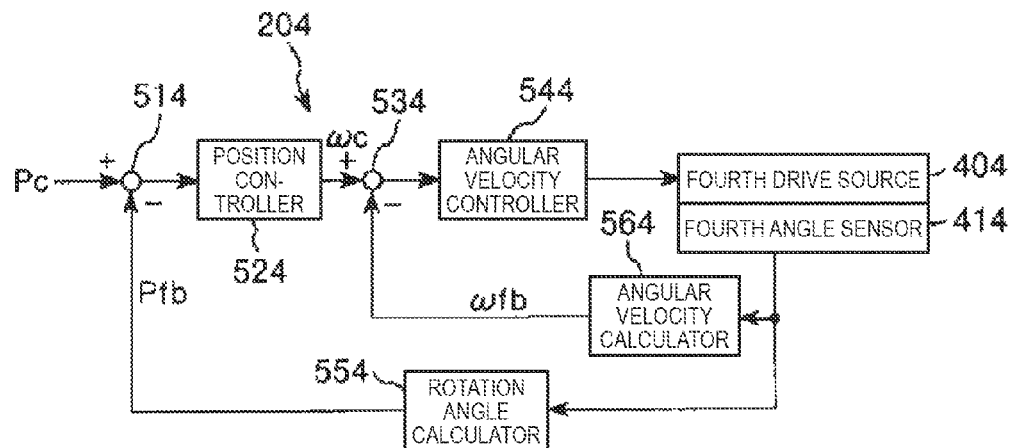


FIG. 8

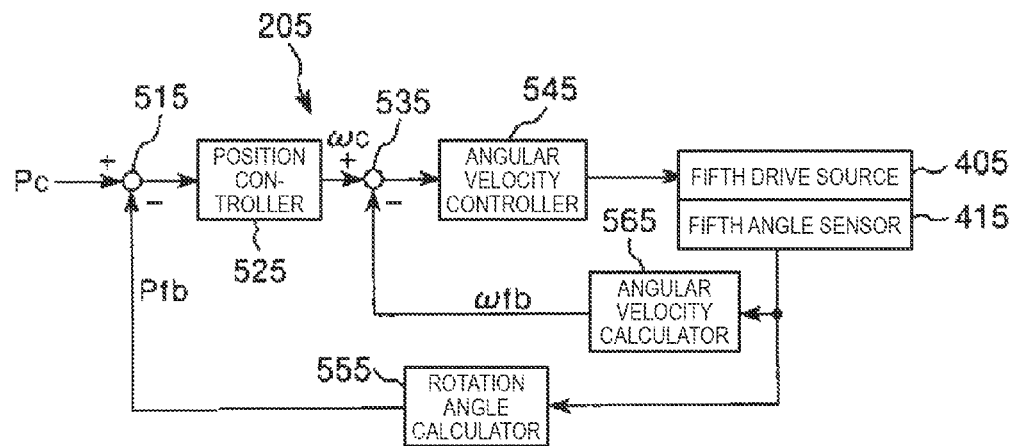


FIG. 9

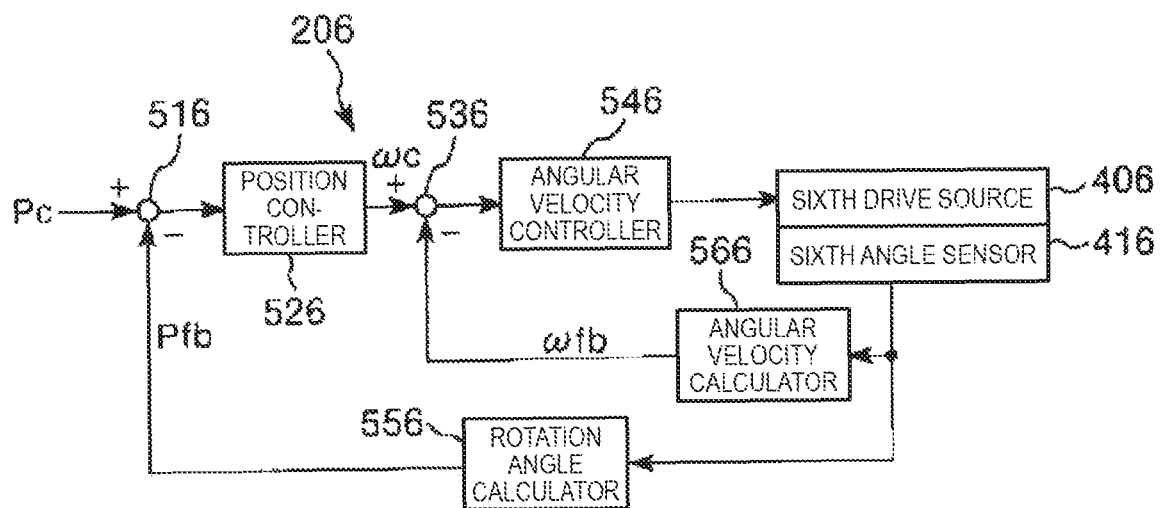


FIG.10

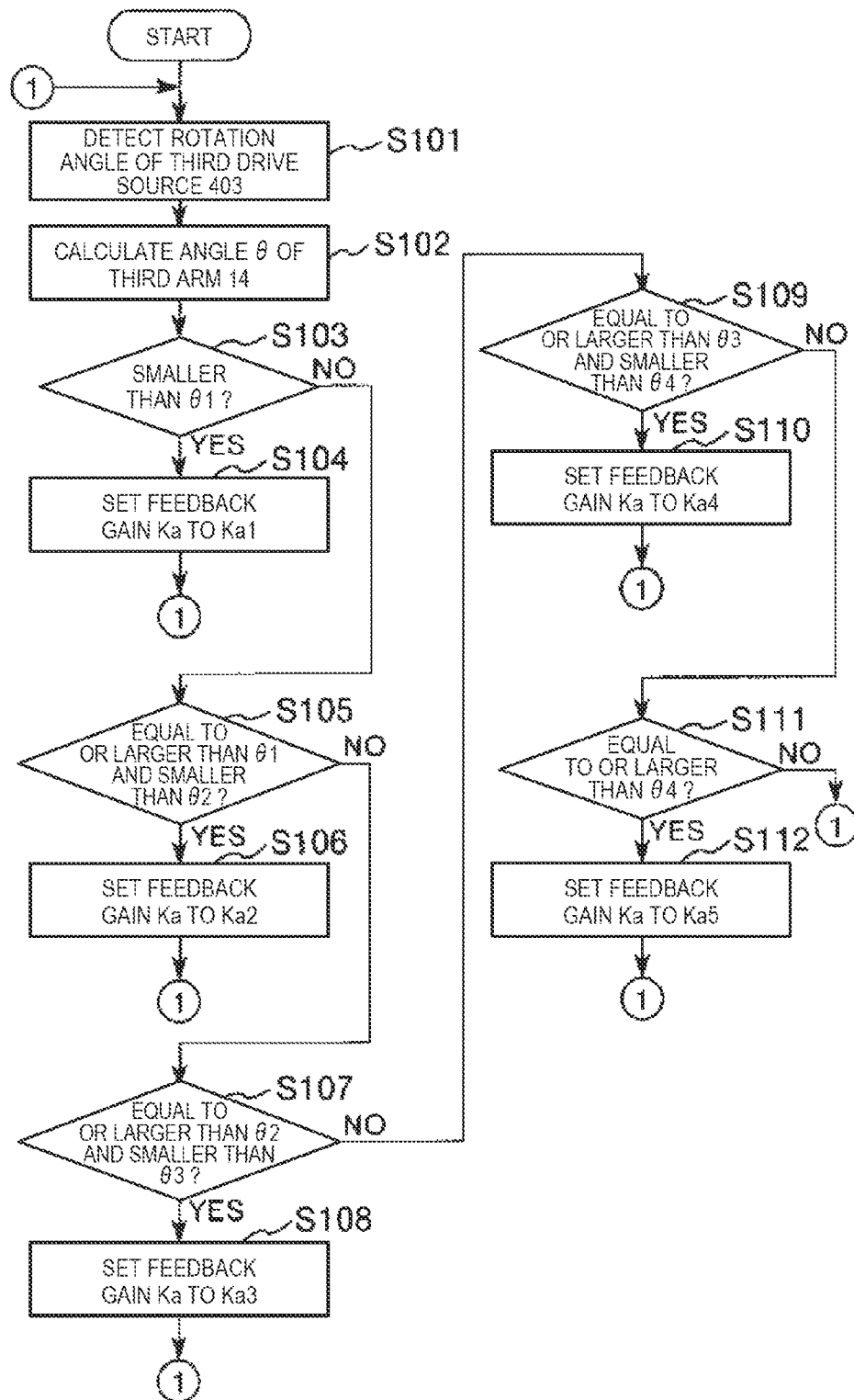


FIG.11

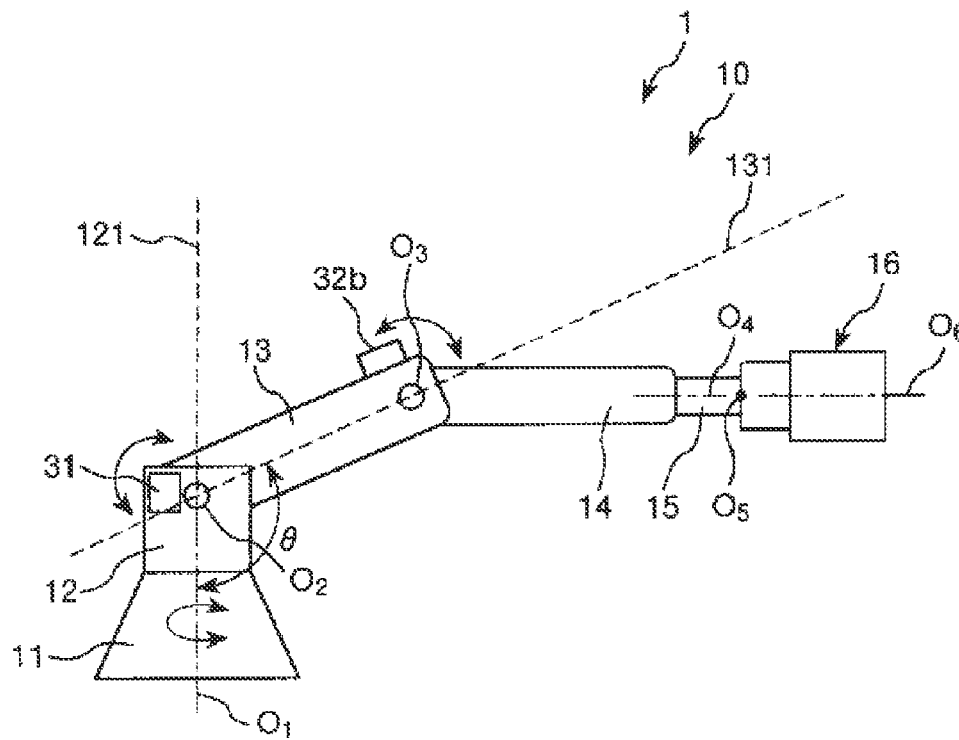


FIG.12

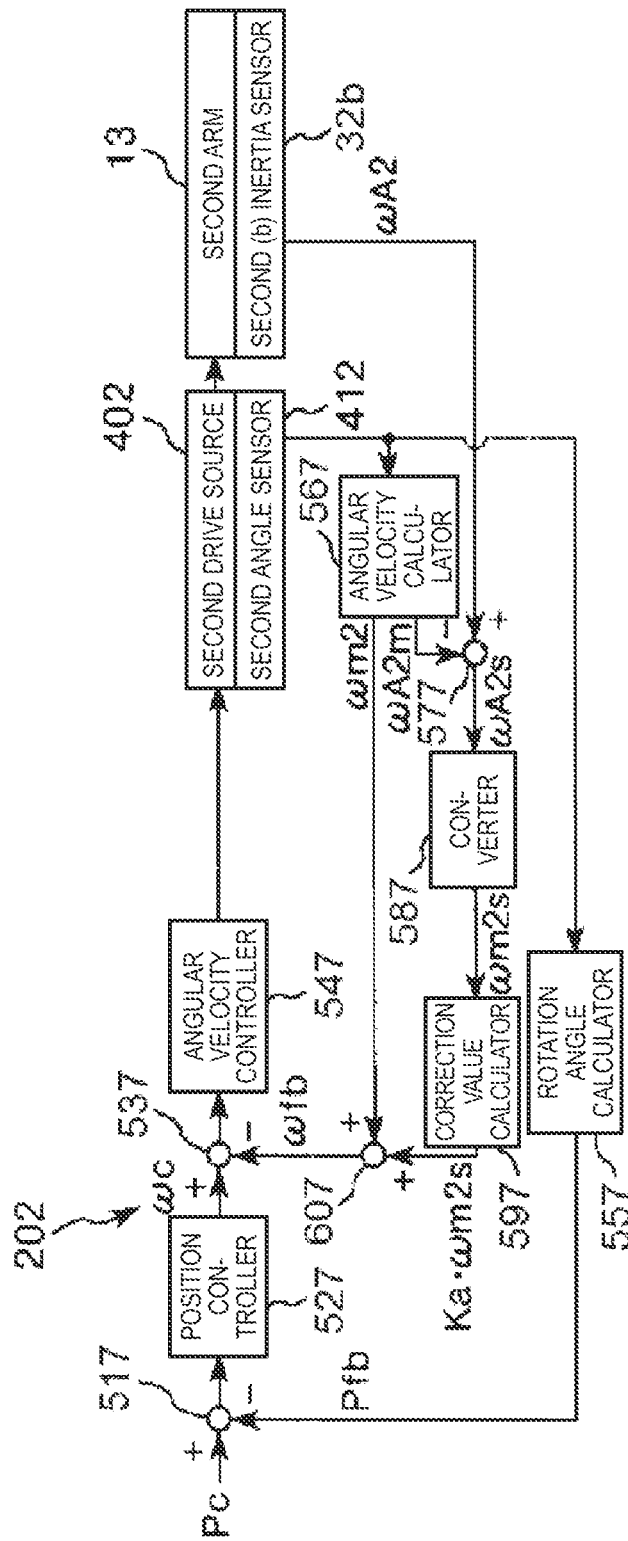


FIG.13

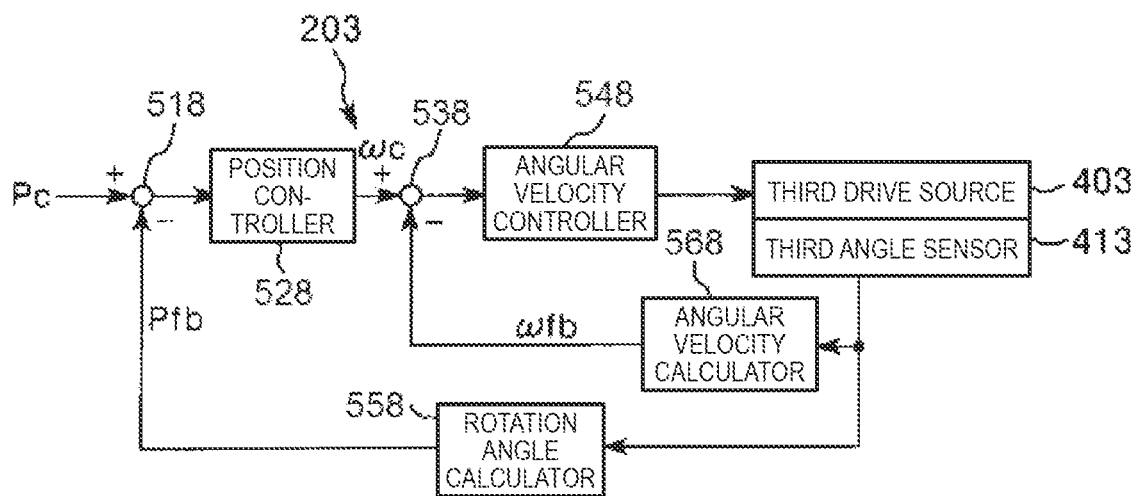


FIG.14

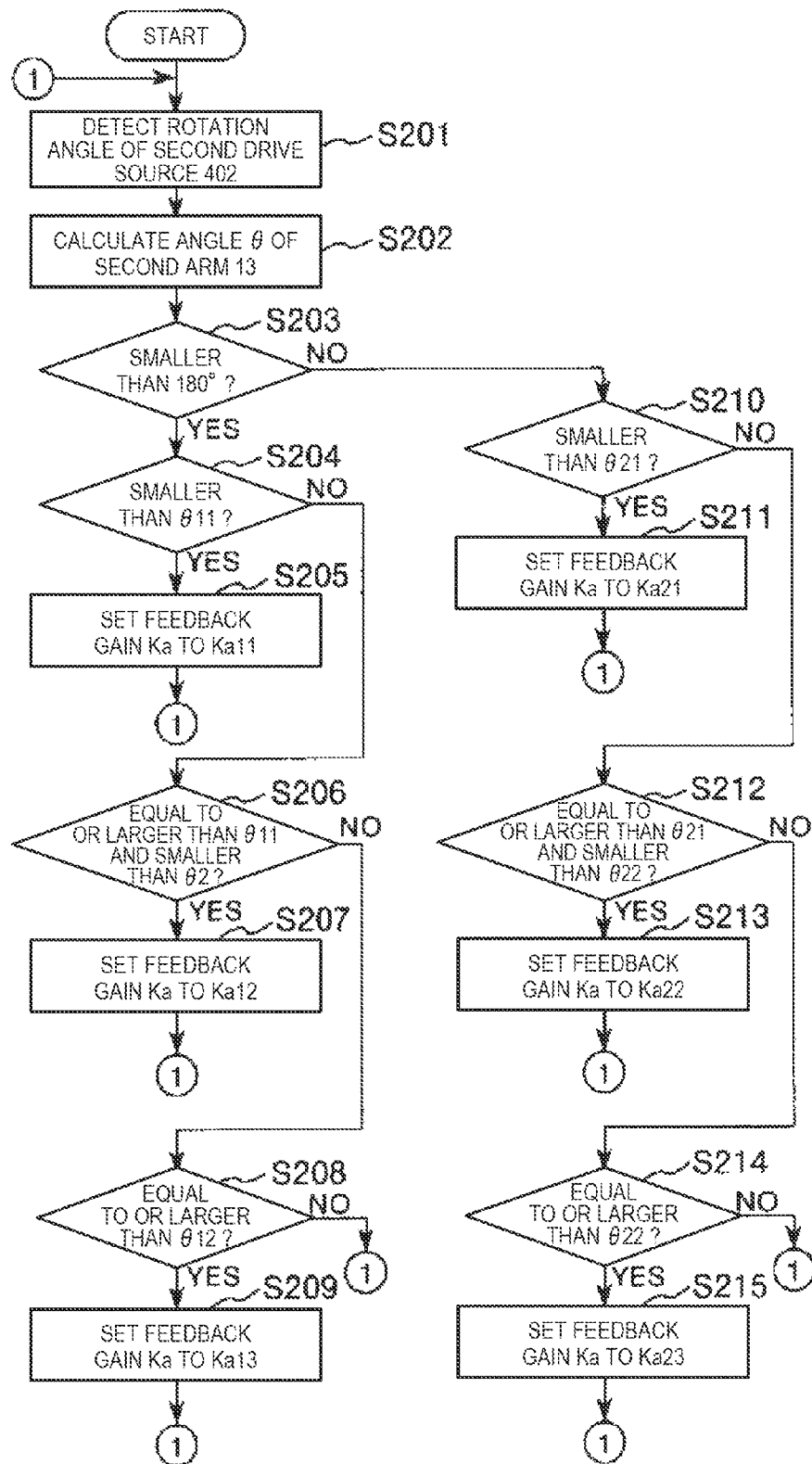


FIG.15

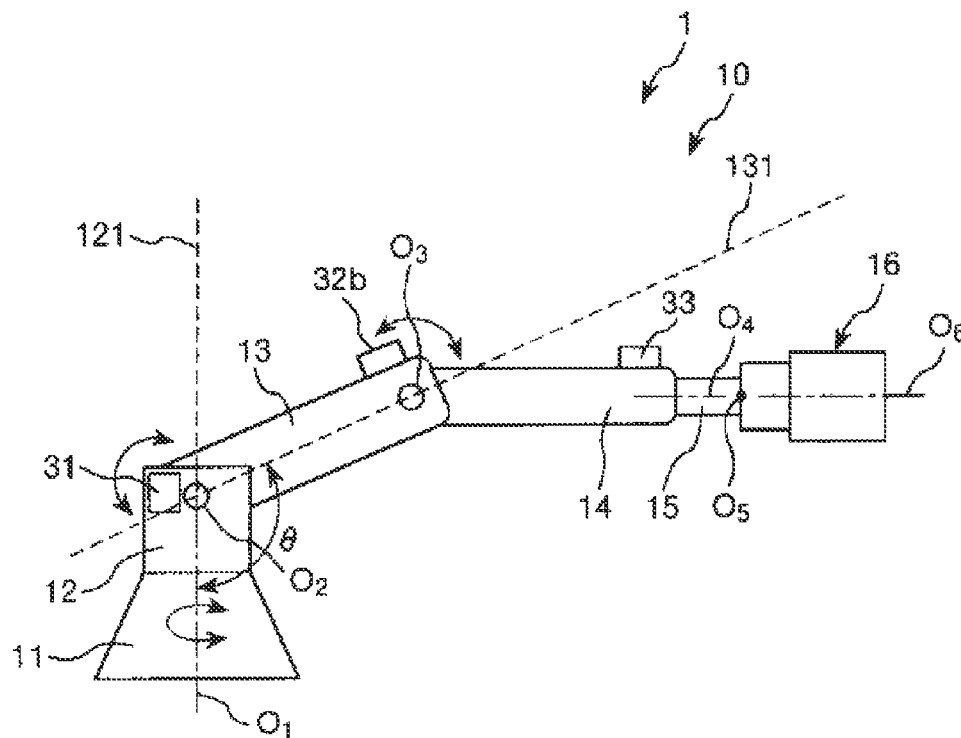


FIG. 16

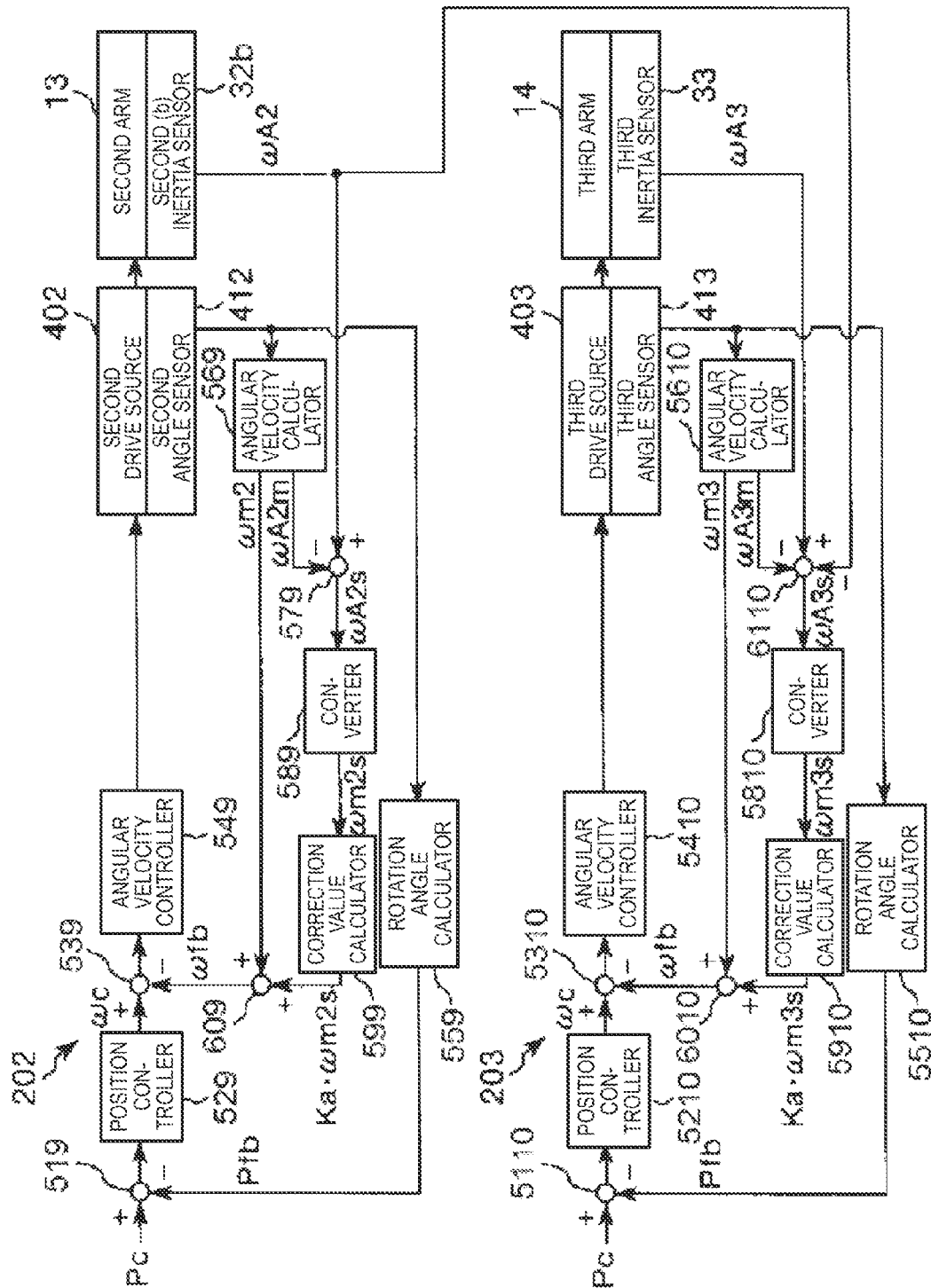


FIG.17

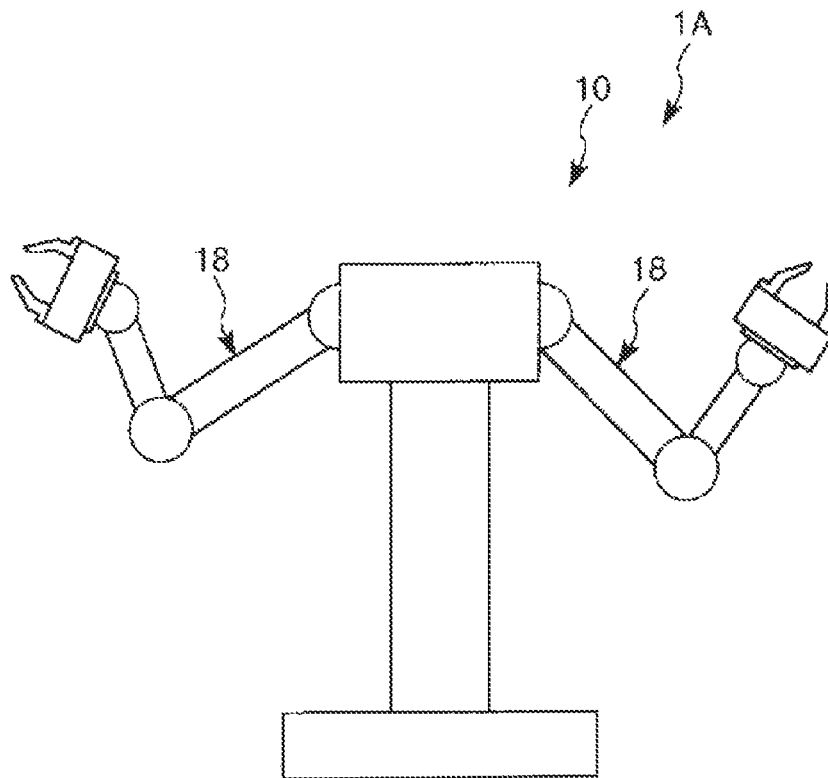


FIG.18

1 ROBOT

BACKGROUND

1. Technical Field

The present invention relates to a robot.

2. Related Art

In the related art, a robot having a base and a plurality of arm link portions is known (for example, refer to JP-A-10-100085). Each arm link portion is rotatably coupled to the arm link portion on a base end side via a joint portion, and the arm link portion closest to the base side is rotatably coupled to the base via a joint portion.

In such a robot, the rigidity of the joint portion that couples the base and the arm link portion or the rigidity of the joint portion that couples the arm link portion and the arm link portion is low compared to the base or the arm link portions under the influence of spring elements of the joint portions. For the reason, there is a problem in that vibration may be easily generated in the arm link portions due to the rotation of the arm link portions or disturbance applied to the arm link portions.

Thus, in the robot described in JP-A-10-100085, an acceleration sensor is installed at a tip portion of the arm link portion closest to a tip side of the robot, compensation components of the respective joint portions that compensate command values to motors of the respective joint portions so as to suppress the vibration generated at the tip portion of the arm link portion closest to the tip side are calculated on the basis of the acceleration detected by the acceleration sensor, and the calculated compensation components of the respective joint portions are subtracted from the command values of the corresponding respective joint portions.

However, the robot described in JP-A-10-100085 has the following drawbacks.

First, since the acceleration sensor is installed at the tip portion of the arm link portion closest to the tip side, the acceleration detected by the acceleration sensor is converted and corrected into those for the respective joint portions. At this time, since it is necessary to perform coordinate axis transformation referred to as the Jacobi's transformation, and matrix calculation having a number of products of sine and cosine as factors is required, the amount of calculation becomes huge. Since it is necessary to calculate the factors according to the rotation angles of the motors of the respective joint portions that change every moment, it is always necessary to execute huge calculation. Accordingly, there is a drawback in that response speed becomes slow.

Additionally, since accurate acceleration or speed cannot be fed back if calculation precision declines, vibration suppression capability may decline or control performance may be impaired. For this reason, there is a restriction on the design of a control system in that a high-speed computing unit is required, for example.

Additionally, in the calculation of the coordinate axis transformation, there is a region (incalculable region) with no coordinate axis transformation solution referred to as a singular point. In the region, the vibration suppression capability may decline or vibration may be increased instead.

Additionally, for example, even when the posture of an arm link portion varies, such as when the arm link portion is extended and when the arm link portion is folded, the same control is performed. Thus, it is difficult to precisely suppress vibration while stabilizing control.

2 SUMMARY

An advantage of some aspects of the invention is to provide a robot that can easily and reliably suppress vibration in the robot according to the posture of an arm.

Application Example 1

A robot according to this application example includes a base; a first arm that is coupled to the base and rotates with a first rotation axis as an axial center; a second arm that is coupled to the first arm and rotates with a second rotation axis in a direction different from the first rotation axis as an axial center; a third arm that rotates with a third rotation axis in a direction parallel to the second rotation axis as an axial center; a first drive source that rotates the first arm through a first angular velocity command; a first inertia sensor that is installed at the first arm and detects the angular velocity or acceleration of the first rotation axis of the first arm; a first angle sensor that detects the rotation angle of the first drive source; a second drive source that rotates the second arm through a second angular velocity command; a second angle sensor that detects the rotation angle of the second drive source; a third drive source that rotates the third arm through a third angular velocity command; a second (a) inertia sensor that is installed at the third arm and detects the angular velocity or acceleration of the second rotation axis of the third arm; a third angle sensor that detects the rotation angle of the third drive source; a posture detection unit that detects the posture of the third arm with the second arm as a reference and derives a feedback gain; a first drive source control unit that feeds back a first correction component, which is derived from an angular velocity $\omega A1$ of the first rotation axis of the first arm obtained from the first inertia sensor and an angular velocity $\omega A1m$ of the first rotation axis of the first arm obtained from the first angle sensor, and controls the first drive source; and a second drive source control unit that feeds back a second correction component, which is obtained by multiplying a value, which is obtained by subtracting an angular velocity $\omega A2m$ of the second rotation axis of the second arm obtained from the second angle sensor and an angular velocity $\omega A3m$ of the third rotation axis of the third arm obtained from the third angle sensor from an angular velocity $\omega A3$ of the second rotation axis of the third arm obtained from the second (a) inertia sensor, or a value derived from the obtained value, by the feedback gain, and controls the second drive source.

Accordingly, the vibration in the robot can be more effectively and reliably suppressed by adjusting the feedback gain according to the posture of an arm.

That is, huge calculation is unnecessary, and thereby, response speed in the control of the robot can be increased. Additionally, since calculation in which a singular point is present is unnecessary, the control of the robot can be reliably performed, and vibration can be reliably suppressed.

Additionally, compared to a case where the inertia sensors are installed at the respective arms and the control of suppressing the vibration in each arm is performed on each arm, the number of the inertia sensors can be reduced, costs can be reduced, and circuit configuration can be simplified.

Additionally, since the second drive source control unit performs the control that feeds back the angular velocities $\omega A3$, $\omega A2m$, and $\omega A3m$ to control the second drive source, that is, suppresses vibration on the second drive source that rotates the second arm, using the detection result of the second (a) inertia sensor installed at the third arm on the tip side where a larger vibration than the second arm is generated, the effect of suppressing the vibration can be enhanced. Addi-

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tionally, the effect of suppressing the vibration can be enhanced by controlling the second drive source that rotates the second arm closer to the base end side than the third arm.

Particularly, since the second drive source control unit adjusts the feedback gain in the feedback control according to the posture of the third arm with the second arm as a reference, vibration can be reliably and effectively suppressed according to the posture of the third arm.

Application Example 2

In the robot according to the application example, it is preferable that the robot further includes the first drive source control unit that feeds back the first correction component, which is obtained by multiplying a value, which is obtained by subtracting the angular velocity $\omega A1m$ from the angular velocity $\omega A1$, or a value derived from the obtained value, by a feedback gain, and controls the first drive source.

Since the feedback gain is adjusted even in the first drive source control unit together with the second drive source control unit, the vibration in the robot can be more effectively suppressed.

Application Example 3

In the robot according to the application example, it is preferable that the robot further includes the posture detection unit that includes the third angle sensor and detects the angle θ formed between the axis of the second arm and the axis of the third arm.

Since the third angle sensor detects the angle θ formed between the axis of the second arm and the axis of the third arm, the number of parts can be reduced, configuration can be simplified, and the posture of the third arm can be more reliably detected.

Application Example 4

In the robot according to the application example, it is preferable that the robot further includes the posture detection unit that detects the angle θ formed between the axis of the second arm and the axis of the third arm, and increases the feedback gain as the angle θ approaches 180° .

Accordingly, vibration can be more reliably suppressed according to the posture of the third arm.

Application Example 5

In the robot according to the application example, it is preferable that the robot further includes the posture detection unit that adjusts the feedback gain, on the basis of the mass of an end effector or the mass of the end effector and an object to be gripped by the end effector.

Accordingly, the vibration can be reliably suppressed according to the mass.

Application Example 6

In robot according to the application example, it is preferable that the robot further includes the posture detection unit that decreases the feedback gain as the mass becomes larger.

Accordingly, the vibration can be more reliably suppressed according to the mass.

Application Example 7

A robot according to this application example includes a base; a first arm that is coupled to the base and rotates with a

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first rotation axis as an axial center; a second arm that is coupled to the first arm and rotates with a second rotation axis in a direction different from the first rotation axis as an axial center; a first drive source that rotates the first arm through a first angular velocity command; a first inertia sensor that is installed at the first arm and detects the angular velocity or acceleration of the first rotation axis of the first arm; a first angle sensor that detects the rotation angle of the first drive source; a second drive source that rotates the second arm through a second angular velocity command; a second angle sensor that detects the rotation angle of the second drive source; a second (b) inertia sensor that is installed at the second arm and detects the angular velocity or acceleration of the second rotation axis of the second arm; a posture detection unit that detects the posture of the second arm with the first arm as a reference and derives a feedback gain; a first drive source control unit that feeds back a first correction component, which is obtained by multiplying a value, which is obtained by subtracting an angular velocity $\omega A1m$ of the first rotation axis of the first arm obtained from a result of the first angle sensor from an angular velocity $\omega A1$ of the first rotation axis of the first arm obtained from the first inertia sensor, or a value derived from the obtained value, by the feedback gain, and controls the first drive source; and a second drive source control unit that feeds back a second correction component, which is derived from an angular velocity $\omega A2$ of the second rotation axis of the second arm obtained from the second (b) inertia sensor, and an angular velocity $\omega A2m$ of the second rotation axis of the second arm obtained from the second angle sensor, and controls the second drive source.

Accordingly, the vibration in the robot can be easily and reliably suppressed according to the posture of an arm.

That is, huge calculation is unnecessary, and thereby, response speed in the control of the robot can be increased. Additionally, since calculation in which a singular point is present is unnecessary, the control of the robot can be reliably performed, and vibration can be reliably suppressed.

Additionally, since the inertia sensors are installed at the respective arms and the control of suppressing the vibration in each arm is performed on the respective arms, the vibration in the robot can be more reliably suppressed.

Particularly, since the first drive source control unit adjusts the feedback gain in the feedback control according to the posture of the second arm with respect to the first arm, vibration can be reliably suppressed according to the posture of the second arm.

Application Example 8

In the robot according to the application example, it is preferable that the robot further includes the second drive source control unit that feeds back the second correction component, which is obtained by multiplying a value, which is obtained by subtracting the angular velocity $\omega A2m$ from the angular velocity $\omega A2$, or a value derived from the obtained value, by a feedback gain, and controls the second drive source.

Since the feedback gain is adjusted even in the second drive source control unit together with the first drive source control unit, the vibration in the robot can be more effectively suppressed.

Application Example 9

In the robot according to the application example, it is preferable that the robot further includes the posture detection

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unit that includes the second angle sensor and detects the angle θ formed between the axis of the first arm and the axis of the second arm.

Since the second angle sensor detects the angle θ formed between the axis of the first arm and the axis of the second arm, the number of parts can be reduced, configuration can be simplified, and the posture of the second arm can be more reliably detected.

Application Example 10

In the robot according to the application example, it is preferable that the robot further includes the posture detection unit that detects the angle θ formed between the axis of the first arm and the axis of the second arm and that increases the feedback gain as the angle θ approaches 90° within a range in which the angle θ is equal to or larger than 0° and smaller than 180° or increases the feedback gain as the angle θ approaches 270° within a range in which the angle θ is equal to or larger than 180° and smaller than 360° .

Accordingly, vibration can be more reliably suppressed according to the posture of the second arm.

Application Example 11

In the robot according to the application example, it is preferable that the robot further includes the posture detection unit that adjusts the feedback gain, on the basis of the mass of an end effector or the mass of the end effector and an object to be gripped by the end effector.

Accordingly, the vibration can be reliably suppressed according to the mass.

Application Example 12

In the robot according to the application example, it is preferable that the robot further includes the posture detection unit that increases the feedback gain as the mass becomes larger.

Accordingly, the vibration can be more reliably suppressed according to the mass.

Application Example 13

In the robot according to the application example, it is preferable that the robot further includes a third arm that is coupled to the second arm so as to be rotatable with a third rotation axis parallel to the second rotation axis as an axial center; a third drive source that rotates the third arm; a third inertia sensor that is installed at the third arm and detects the angular velocity or acceleration of the second rotation axis of the third arm; a third angle sensor that detects the rotation angle of the third drive source; and a third drive source control unit that feeds back a third correction component, which is derived from an angular velocity $\omega A3$ of the second rotation axis of the third arm obtained from the third inertia sensor, an angular velocity $\omega A2$ of the second rotation axis of the second arm obtained from the second (b) inertia sensor, and an angular velocity $\omega A3m$ of the third rotation axis of the third arm obtained from the third angle sensor, and controls the third drive source.

Accordingly, the vibration in the robot can be more reliably suppressed.

Application Example 14

In the robot according to the application example, it is preferable that the robot further includes the third drive

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source control unit that feeds back the third correction component, which is obtained by multiplying a value, which is obtained by subtracting the angular velocity $\omega A2$ and the angular velocity $\omega A3m$ from the angular velocity $\omega A3$, or a value derived from the obtained value, by a feedback gain, and controls the third drive source.

Accordingly, the vibration in the robot can be more reliably suppressed.

Application Example 15

In the robot according to the application example, it is preferable that the robot further includes the first inertia sensor installed at a tip portion of the first arm; and the second (b) inertia sensor installed at a tip portion of the second arm.

Accordingly, since the first inertia sensor detects the angular velocity or acceleration of the first arm in a region where the vibration in the first arm is at the maximum and the second (b) inertia sensor detects the angular velocity or acceleration of the second arm in a region where the vibration in the second arm is at the maximum, the vibration in the robot can be more reliably suppressed.

Application Example 16

In the robot according to the application example, it is preferable that the robot further includes the first inertia sensor installed at a tip portion of the first arm; and the second (a) inertia sensor installed at a tip portion of the third arm.

Accordingly, since the first inertia sensor detects the angular velocity or acceleration of the first arm in a region where the vibration in the first arm is at the maximum and the second (a) inertia sensor detects the angular velocity or acceleration of the third arm in a region where the vibration in the third arm is at the maximum, the vibration in the robot can be more reliably suppressed.

Application Example 17

In the robot according to the application example, it is preferable that the robot further includes the first arm that rotates with the first rotation axis, which coincides with the normal line of an installation surface of the base, as an axial center.

Accordingly, the control of the robot can be easily performed.

Application Example 18

In the robot according to the application example, preferably, the robot further includes the second arm that rotates with the second rotation axis, which is orthogonal to the first rotation axis or parallel to an axis orthogonal to the first rotation axis, as an axial center.

Accordingly, the robot can be easily controlled.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be described with reference to the accompanying drawings, wherein like numbers reference like elements.

FIG. 1 is a perspective view when a first embodiment of a robot of the invention is viewed from the front side.

FIG. 2 is a perspective view when the robot shown in FIG. 1 is viewed from the back side.

FIG. 3 is a schematic view of the robot shown in FIG. 1.

FIG. 4 is a schematic view of the robot shown in FIG. 1.

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FIG. 5 is a block diagram of main portions of the robot shown in FIG. 1.

FIG. 6 is a block diagram of main portions of the robot shown in FIG. 1.

FIG. 7 is a block diagram of main portions of the robot shown in FIG. 1.

FIG. 8 is a block diagram of main portions of the robot shown in FIG. 1.

FIG. 9 is a block diagram of main portions of the robot shown in FIG. 1.

FIG. 10 is a block diagram of main portions of the robot shown in FIG. 1.

FIG. 11 is a flowchart showing the control operation of a control device of the robot shown in FIG. 1.

FIG. 12 is a schematic view showing a third embodiment of the robot of the invention.

FIG. 13 is a block diagram of main portions of the robot shown in FIG. 12.

FIG. 14 is a block diagram of main portions of the robot shown in FIG. 12.

FIG. 15 is a flowchart showing the control operation of a control device of the robot shown in FIG. 12.

FIG. 16 is a schematic view showing a fifth embodiment of the robot of the invention.

FIG. 17 is a block diagram of main portions of the robot shown in FIG. 16.

FIG. 18 is a front view showing another configuration example of the robot of the invention.

DESCRIPTION OF EXEMPLARY EMBODIMENTS

A robot of the invention will be described below in detail on the basis of preferred embodiments shown in the accompanying drawings.

First Embodiment

FIG. 1 is a perspective view when a first embodiment of a robot of the invention is viewed from the front side. FIG. 2 is a perspective view when the robot shown in FIG. 1 is viewed from the back side. FIGS. 3 and 4 are schematic views of the robot shown in FIG. 1, respectively. FIG. 5 is a block diagram of main portions of the robot shown in FIG. 1. FIGS. 6 to 10 are block diagrams of the main portions of the robot shown in FIG. 1, respectively. FIG. 11 is a flowchart showing the control operation of a control device of the robot shown in FIG. 1.

In addition, in the following, for the convenience of description, the upper side in FIGS. 1 to 4 and FIG. 6 is referred to as “upper” or “upside” and the lower side is referred to as “lower” or “downside”. Additionally, the base side in FIGS. 1 to 4 and FIG. 6 is referred to as a “base end”, and the opposite side is referred to as a “tip”. Additionally, the rotation axes O2 and O3 are shown in an exaggerated manner in FIG. 4, respectively. Additionally, inertia sensors 31 and 32a are shown outside arms 12 and 14 in FIG. 4, respectively, in order to clarify the presence of the sensors.

A robot (industrial robot) 1 shown in FIGS. 1 to 4 can be used for, for example, a manufacturing process that manufactures precision mechanical equipment, such as a wrist watch, and has a robot body 10 and a control device (control unit) 20 (refer to FIG. 5) that controls the operation of the robot body 10. The robot body 10 and the control device 20 are electrically connected. Additionally, the control device 20 can be constituted by, for example, personal computers (PC) in which a central processing unit (CPU) is built. In addition, the control device 20 will be described below in more detail.

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The robot body 10 includes a base 11, four arms (links) 12, 13, 14, and 15, a wrist (link) 16, and six drive sources 401, 402, 403, 404, 405, and 406. The robot body 10 is a vertical multi-joint (six-axis) robot (robot body) in which the base 11, the arms 12, 13, 14, and 15, and the wrist 16 are coupled together in the order from a base end side toward a tip side. In the vertical multi-joint robot, the base 11, the arms 12 to 15, and the wrist 16 can also be collectively referred to as “arms”, and the arm 12, the arm 13, the arm 14, the arm 15, and the wrist 16 can be referred to as a “first arm”, a “second arm”, a “third arm”, a “fourth arm”, and a “fifth or sixth arm”, respectively. In addition, the wrist 16 may have the fifth arm and the sixth arm. An end effector or the like can be attached to the wrist 16.

As shown in FIGS. 3 and 4, the arms 12 to 15 and the wrist 16 are supported so as to be independently displaceable with respect to the base 11. The lengths of the arms 12 to 15 and the wrist 16 are not particularly limited, respectively. However, in the illustrated configuration, the lengths of the arms 12 to 14 are set to be larger than those of the other arm 15 and the wrist 16. In addition, for example, the length of the third arm 14 may be made smaller than the lengths of the first arm 12 and the second arm 13.

The base 11 and the first arm 12 are coupled together via a joint 171. The first arm 12 has a first rotation axis O1 parallel to the vertical direction as a rotation center, and is rotatable with respect to the base 11 around the first rotation axis O1. The first rotation axis O1 coincides with the normal line of an upper surface of a floor 101 that is an installation surface of the base 11. The rotation around the first rotation axis O1 is performed by the driving of the first drive source 401. Additionally, the first drive source 401 is driven by a motor 401M and a cable (not shown), and the motor 401M is controlled by the control device 20 via a motor driver 301 that is electrically connected thereto (refer to FIG. 5). The driving from the motor 401M may be transmitted to the first drive source 401 by a speed reducer (not shown) provided together with the motor 401M, and the speed reducer may be omitted.

The first arm 12 and the second arm 13 are coupled together via a joint 172. The second arm 13 is rotatable with respect to the first arm 12 with the second rotation axis O2 parallel to the horizontal direction as an axial center. The second rotation axis O2 is orthogonal to the first rotation axis O1. The rotation around the second rotation axis O2 is performed by the driving of the second drive source 402. Additionally, the second drive source 402 is driven by a motor 402M and a cable (not shown), and the motor 402M is controlled by the control device 20 via a motor driver 302 that is electrically connected thereto (refer to FIG. 5). The driving from the motor 402M may be transmitted to the second drive source 402 by a speed reducer (not shown) provided in addition to the motor 402M, and the speed reducer may be omitted. In addition, the rotation axis O2 may be parallel to an axis orthogonal to the rotation axis O1.

The second arm 13 and the third arm 14 are coupled together via a joint 173. The third arm 14 has a rotation axis O3 parallel to the horizontal direction as a rotation center, and is rotatable with respect to the second arm 13 around the third rotation axis O3. The third rotation axis O3 is parallel to the second rotation axis O2. The rotation around the third rotation axis O3 is performed by the driving of the third drive source 403. Additionally, the third drive source 403 is driven by a motor 403M and a cable (not shown), and the motor 403M is controlled by the control device 20 via a motor driver 303 that is electrically connected thereto (refer to FIG. 5). The driving from the motor 403M may be transmitted to the third drive

source **403** by a speed reducer (not shown) provided in addition to the motor **403M**, and the speed reducer may be omitted.

The third arm **14** and the fourth arm **15** are coupled together via a joint **174**. The fourth arm **15** has a fourth rotation axis **O4** parallel to the direction of a central axis of the third arm **14** as a rotation center, and is rotatable with respect to the third arm **14** (base **11**) around the fourth rotation axis **O4**. The fourth rotation axis **O4** is orthogonal to the third rotation axis **O3**. The rotation around the fourth rotation axis **O4** is performed by the driving of the fourth drive source **404**. Additionally, the fourth drive source **404** is driven by a motor **404M** and a cable (not shown), and the motor **404M** is controlled by the control device **20** via a motor driver **304** that is electrically connected thereto (refer to FIG. 5). The driving from the motor **404M** may be transmitted to the fourth drive source **404** by a speed reducer (not shown) provided together with the motor **404M**, and the speed reducer may be omitted. In addition, the fourth rotation axis **O4** may be parallel to an axis orthogonal to the third rotation axis **O3**.

The fourth arm **15** and the wrist **16** are coupled together via a joint **175**. The wrist **16** has a fifth rotation axis **O5** parallel to the horizontal direction (y-axis direction) as a rotation center, and is rotatable with respect to the fourth arm **15** around the fifth rotation axis **O5**. The fifth rotation axis **O5** is orthogonal to the fourth rotation axis **O4**. The rotation around the fifth rotation axis **O5** is performed by the driving of the fifth drive source **405**. Additionally, the fifth drive source **405** is driven by a motor **405M** and a cable (not shown), and the motor **405M** is controlled by the control device **20** via a motor driver **305** that is electrically connected thereto (refer to FIG. 5). The driving from the motor **405M** may be transmitted to the fifth drive source **405** by a speed reducer (not shown) provided together with the motor **405M**, and the speed reducer may be omitted. Additionally, the wrist **16** has a sixth rotation axis **O6** vertical to the fifth rotation axis **O5** as a rotation center, and is also rotatable via a joint **176** around the sixth rotation axis **O6**. The rotation axis **O6** is orthogonal to the rotation axis **O5**. The rotation around the sixth rotation axis **O6** is performed by the driving of the sixth drive source **406**. Additionally, the sixth drive source **406** is driven by a motor **406M** and a cable (not shown), and the motor **406M** is controlled by the control device **20** via a motor driver **306** that is electrically connected thereto (refer to FIG. 5). The driving from the motor **406M** may be transmitted to the sixth drive source **406** by a speed reducer (not shown) provided in addition to the motor **406M**, and the speed reducer may be omitted. In addition, the fifth rotation axis **O5** may be parallel to an axis orthogonal to the fourth rotation axis **O4**, and the sixth rotation axis **O6** may be parallel to an axis orthogonal to the fifth rotation axis **O5**.

Additionally, the first inertia sensor **31** is installed at the first arm **12**. The first inertia sensor **31** detects the angular velocity of the first arm **12** around the first rotation axis **O1**. Although the installation position of the first inertia sensor **31** at the first arm **12** is not particularly limited, a tip portion of the first arm **12** is preferable. In the present embodiment, the first inertia sensor **31** is installed at the tip portion inside the first arm **12**. Since the vibration in the third arm **12** becomes the maximum at the tip portion of the third arm, this can more reliably suppress the vibration in the robot **1**. In addition, it is obvious that the first inertia sensor **31** may be installed at a base end portion of the first arm **12**.

Additionally, the second (a) inertia sensor **32a** is installed at the third arm **14**. The second (a) inertia sensor **32a** detects the angular velocity of the third arm **14** around the second rotation axis **O2**. Although the installation position of the second (a) inertia sensor **32a** at the third arm **14** is not par-

ticularly limited, a tip portion of the third arm **14** is preferable. In the present embodiment, the second (a) inertia sensor **32a** is installed at the tip portion inside the third arm **14**. Since the vibration in the third arm **14** becomes the maximum at the tip portion of the third arm, this can more reliably suppress the vibration in the robot **1**. In addition, it is obvious that the second (a) inertia sensor **32a** may be installed at a base end portion of the third arm **14**.

Additionally, the first inertia sensor **31** and the second (a) inertia sensor **32a** are not particularly limited, respectively, and in the present embodiment, for example, a gyroscope sensor, an acceleration sensor, or the like can be used.

Here, in the robot **1**, the vibration in the whole robot **1** is suppressed by suppressing the vibration in the arms **12**, **13**, and **14**. However, in order to suppress the vibration in the arms **12**, **13**, and **14**, inertia sensors are not installed at all the arms **12**, **13**, and **14**. As mentioned above, the first inertia sensor **31** and the second (a) inertia sensor **32a** are installed only at the arms **12** and **14**, and the operation of the drive sources **401** and **402** is controlled on the basis of detection results of the first inertia sensor **31** and the second (a) inertia sensor **32a**. Accordingly, compared to a case where inertia sensors are installed at all the arms **12**, **13**, and **14**, the number of the inertia sensors can be reduced, costs can be reduced, and circuit configuration can be simplified.

A first angle sensor **411**, a second angle sensor **412**, a third angle sensor **413**, a fourth angle sensor **414**, a fifth angle sensor **415**, and a sixth angle sensor **416** are provided at respective motors or speed reducers in the drive sources **401** to **406**. Encoders, rotary encoders, or the like can be used as the angle sensors. The angle sensors **411** to **416** detect the rotation angles of rotating shafts of the motors or speed reducers of the drive sources **401** to **406**, respectively. The motors of the drive sources **401** to **406** are not particularly limited, respectively. For example, it is preferable to use servo motors, such as AC servo motors or DC servo motors. Additionally, the respective cables may be inserted through the robot body **10**, respectively.

As shown in FIG. 5, the robot body **10** is electrically connected to the control device **20**. That is, the drive sources **401** to **406**, the angle sensors **411** to **416**, and the inertia sensors **31** and **32a** are electrically connected to the control device **20**, respectively.

The control device **20** can independently operate the arms **12** to **15** and the wrist **16**, respectively, that is, can independently control the drive sources **401** to **406** via the motor drivers **301** to **306**, respectively. In the case, the control device **20** performs detection by the angle sensors **411** to **416**, the first inertia sensor **31**, and the second (a) inertia sensor **32a**, and controls the driving, for example, angular velocity, rotation angle, or the like of the drive sources **401** to **406** on the basis of the detection results, respectively. A control program is stored in advance in a recording medium built in the control device **20**.

As shown in FIG. 1 and FIG. 2, when the robot **1** is a vertical multi-joint robot, the base **11** is a portion that is located on the lowermost side of the vertical multi-joint robot and is fixed to the floor **101** of an installation space. The fixing method is not particularly limited, and for example, in the present embodiment shown in FIGS. 1 and 2, a fixing method using a plurality of bolts **111** is used. In addition, a fixing place in the installation space of the base **11** can also be the wall or ceiling of the installation space other than the floor.

The base **11** has a hollow base body (housing) **112**. The base body **112** can be separated into a cylindrical portion **113** that forms a cylindrical shape, and a box-shaped portion **114** that is integrally formed at an outer peripheral portion of the

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cylindrical portion 113 and forms a box shape. For example, the motor 401M and the motor drivers 301 to 306 are stored in such a base body 112.

The arms 12 to 15 have a hollow arm body 2, a drive mechanism 3, and a sealing unit 4, respectively. In addition, in the following, for the convenience of description, the arm body 2, the drive mechanism 3, and the sealing unit 4 of the first arm 12 may be referred to as an “arm body 2a”, a “drive mechanism 3a”, and a “sealing unit 4a”, respectively, the arm body 2, the drive mechanism 3, and the sealing unit 4 of the second arm 13 may be referred to as an “arm body 2b”, a “drive mechanism 3b”, and a “sealing unit 4b”, respectively, the arm body 2, the drive mechanism 3, and the sealing unit 4 of the third arm 14 may be referred to as an “arm body 2c”, a “drive mechanism 3c”, and a “sealing unit 4c”, respectively, and the arm body 2, the drive mechanism 3, and the sealing unit 4 of the fourth arm 15 may be referred to as an “arm body 2d”, a “drive mechanism 3d”, and a “sealing unit 4d”, respectively.

Additionally, the joints 171 to 176 have rotation support mechanisms (not shown), respectively. The rotation support mechanisms are a mechanism that supports one of two arms coupled to each other so as to be rotatable to the other, a mechanism that supports one of the base 11 and the first arm 12 coupled to each other so as to be rotatable to the other, and a mechanism that supports one of the fourth arm 15 and the wrist 16 coupled to each other so as to be rotatable to the other. When the fourth arm 15 and the wrist 16 coupled to each other are taken as an example, the rotation support mechanism can rotate the wrist 16 with respect to the fourth arm 15. Additionally, each rotation support mechanism has a speed reducer (not shown) that reduces the rotating speed of a corresponding motor in a predetermined reduction ratio, and transmits the driving force thereof to a corresponding arm, the wrist body 161 of the wrist 16, and a support ring 162.

The first arm 12 is coupled to an upper end portion (tip portion) of the base 11 in a posture in which the first arm inclines with respect to the horizontal direction. In the first arm 12, the drive mechanism 3a has the motor 402M, and is stored within the arm body 2a. Additionally, the inside of the arm body 2a is hermetically sealed by the sealing unit 4a.

The second arm 13 is coupled to a tip portion of the first arm 12. In the second arm 13, the drive mechanism 3b has the motor 403M, and is stored within the arm body 2b. Additionally, the inside of the arm body 2b is hermetically sealed by the sealing unit 4b.

The third arm 14 is coupled to a tip portion of the second arm 13. In the third arm 14, the drive mechanism 3c has the motor 404M, and is stored within the arm body 2c. Additionally, the inside of the arm body 2c is hermetically sealed by the sealing unit 4c.

The fourth arm 15 is coupled to a tip portion of the third arm 14 in parallel with the direction of a central axis thereof. In the arm 15, the drive mechanism 3d has the motors 405M and 406M, and is stored within the arm body 2d. Additionally, the inside of the arm body 2d is hermetically sealed by the sealing unit 4d.

The wrist 16 is coupled to a tip portion (end portion opposite the base 11) of the fourth arm 15. For example, a manipulator (not shown) that grips precision mechanical equipment, such as a wrist watch, is detachably mounted on a tip portion (an end portion opposite the fourth arm 15) of the wrist 16. In addition, the manipulator is not particularly limited, and includes, for example, a manipulator of a configuration having a plurality of fingers. The robot 1 can convey the precision mechanical equipment by controlling the operation of the

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arms 12 to 15, the wrist 16, or the like with the precision mechanical equipment gripped by the manipulator.

The wrist 16 has the wrist body (sixth arm) 161 that forms a cylindrical shape, and the support ring (fifth arm) 162 that is configured separately from the wrist body 161, is provided at a base end portion of the wrist body 161, and forms a ring shape.

A tip face 163 of the wrist body 161 is a flat surface, and serves as a mounting surface on which the manipulator is mounted. Additionally, the wrist body 161 is coupled to the drive mechanism 3d of the fourth arm 15 via the joint 176, and is rotated around the rotation axis O6 by the driving of the motor 406M of the drive mechanism 3d.

The support ring 162 is coupled to the drive mechanism 3d of the fourth arm 15 via the joint 175, and is rotated around the rotation axis O5 of the whole wrist body 161 by the driving of the motor 405M of the drive mechanism 3d.

Next, the configuration of the control device 20 will be described with reference to FIGS. 5 and 6 to 10.

As shown in FIGS. 5 and 6 to 10, the control device 20 has a first drive source controller (first drive source control unit) (first angular velocity command) 201 that controls the operation of the first drive source 401, a second drive source controller (second drive source control unit) (second angular velocity command) 202 that controls the operation of the second drive source 402, a third drive source controller (third drive source control unit) (third angular velocity command) 203 that controls the operation of the third drive source 403, a fourth drive source controller (fourth drive source control unit) (fourth angular velocity command) 204 that controls the operation of the fourth drive source 404, a fifth drive source controller (fifth drive source control unit) (fifth angular velocity command) 205 that controls the operation of the fifth drive source 405, and a sixth drive source controller (sixth drive source control unit) (sixth angular velocity command) 206 that controls the operation of the sixth drive source 406.

As shown in FIG. 6, the first drive source controller 201 has a subtractor 511, a position controller 521, a subtractor 531, an angular velocity controller 541, a rotation angle calculator 551, an angular velocity calculator 561, a subtractor 571, a converter 581, a correction value calculator 591, and an adder 601.

As shown in FIG. 7, the second drive source controller 202 has a subtractor 512, a position controller 522, a subtractor 532, an angular velocity controller 542, a rotation angle calculator 552, an angular velocity calculator 562, an adder-subtractor 622, a converter 582, a correction value calculator 592, and an adder 602.

As shown in FIG. 7, the third drive source controller 203 has a subtractor 513, a position controller 523, a subtractor 533, an angular velocity controller 543, a rotation angle calculator 553, and an angular velocity calculator 563.

As shown in FIG. 8, the fourth drive source controller 204 has a subtractor 514, a position controller 524, a subtractor 534, an angular velocity controller 544, a rotation angle calculator 554, and an angular velocity calculator 564.

As shown in FIG. 9, the fifth drive source controller 205 has a subtractor 515, a position controller 525, a subtractor 535, an angular velocity controller 545, a rotation angle calculator 555, and an angular velocity calculator 565.

As shown in FIG. 10, the sixth drive source controller 206 has a subtractor 516, a position controller 526, a subtractor 536, an angular velocity controller 546, a rotation angle calculator 556, and an angular velocity calculator 566.

Here, the control device 20 calculates a target position of the wrist 16 on the basis of the contents of processing to be performed by the robot 1, and generates a track for moving the

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wrist 16 to the target position. The control device 20 measures the rotation angles of the respective drive sources 401 to 406 for every predetermined control cycle so that the wrist 16 moves along the generated track, and outputs values calculated on the basis of the measurement results to the drive source controllers 201 to 206 as position commands P_c of the respective drive sources 401 to 406, respectively (refer to FIGS. 6 to 10). In addition, although “values are input, output” or the like are written in the above and the following, this means “signals corresponding to the values are input, output”.

As shown in FIG. 6, in addition to a position command P_c of the first drive source 401, detection signals are input from the first angle sensor 411 and the first inertia sensor 31, respectively, to the first drive source controller 201. The first drive source controller 201 drives the first drive source 401 by a feedback control using the respective detection signals so that a rotation angle (position feedback value P_{fb}) of the first drive source calculated from the detection signal of the first angle sensor 411 becomes the position command P_c and an angular velocity feedback value ω_{fb} to be described below becomes an angular velocity command ω_c to be described below.

That is, the position command P_c is input to the subtractor 511 of the first drive source controller 201, and the position feedback value P_{fb} to be described below is input from the rotation angle calculator 551. In the rotation angle calculator 551, the number of pulses input from the first angle sensor 411 is counted, and the rotation angle of the first drive source 401 according to the counted value is output to the subtractor 511 as the position feedback value P_{fb} . The subtractor 511 outputs a deviation (value obtained by subtracting the position feedback value P_{fb} from a targeted value of the rotation angle of the first drive source 401) between the position command P_c and the position feedback value P_{fb} to the position controller 521.

The position controller 521 performs predetermined calculation processing using the deviation input from the subtractor 511 and a proportional gain that is a predetermined factor, and calculates the targeted value of the angular velocity of the first drive source 401 according to the deviation. The position controller 521 outputs a signal showing the targeted value (command value) of the angular velocity of the first drive source 401 to the subtractor 531 as the angular velocity command (first angular velocity command) ω_c . In addition, in the present embodiment, a proportional control (P control) is performed as the feedback control. However, the feedback control is not limited to this.

The angular velocity command ω_c and the angular velocity feedback value ω_{fb} to be described below are input to the subtractor 531. The subtractor 531 outputs a deviation (value obtained by subtracting the angular velocity feedback value ω_{fb} from the targeted value of the angular velocity of the first drive source 401) between the angular velocity command ω_c and the angular velocity feedback value ω_{fb} to the angular velocity controller 541.

The angular velocity controller 541 performs predetermined calculation processing including integration, using the deviation input from the subtractor 531, a proportional gain that is a predetermined factor, an integration gain, or the like, thereby generating a driving signal (driving current) of the first drive source 401 according to the deviation and supplying the driving signal to the motor 401M via the motor driver 301. In addition, in the present embodiment, the PI control is performed as the feedback control. However, the feedback control is not limited to this.

In this way, the feedback control is performed and the driving current of the first drive source 401 is controlled so

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that the position feedback value P_{fb} is as equal to the position command P_c as possible and the angular velocity feedback value ω_{fb} is as equal to the angular velocity command ω_c as possible.

Next, the angular velocity feedback value ω_{fb} in the first drive source controller 201 will be described.

In the angular velocity calculator 561, an angular velocity ω_{m1} of the first drive source 401 is calculated on the basis of the frequency of a pulse signal input from the first angle sensor 411, and the angular velocity ω_{m1} is output to the adder 601.

Additionally, in the angular velocity calculator 561, an angular velocity ω_{A1m} of the first arm 12 around the rotation axis O1 is calculated on the basis of the frequency of the pulse signal input from the first angle sensor 411, and the angular velocity ω_{A1m} is output to the subtractor 571. In addition, the angular velocity ω_{A1m} is a value obtained by dividing the angular velocity ω_{m1} by a reduction ratio between the motor 401M of the first drive source 401 and the first arm 12, that is, in the joint 171.

Additionally, the angular velocity of the first arm 12 around the rotation axis O1 is detected by the first inertia sensor 31. A detection signal of the first inertia sensor 31, that is, an angular velocity ω_{A1} of the first arm 12 around the rotation axis O1 detected by the first inertia sensor 31 is output to the subtractor 571.

The angular velocity ω_{A1} and the angular velocity ω_{A1m} are input to the subtractor 571, and the subtractor 571 outputs a value ω_{A1s} ($=\omega_{A1}-\omega_{A1m}$) obtained by subtracting the angular velocity ω_{A1m} from the angular velocity ω_{A1} to the converter 581. The value ω_{A1s} is equivalent to a vibration component (vibration angular velocity) of the angular velocity of the first arm 12 around the rotation axis O1. Hereinafter, ω_{A1s} is referred to as a vibration angular velocity. In the present embodiment, a feedback control is performed in which the vibration angular velocity ω_{A1s} (in detail, an angular velocity ω_{m1s} in the motor 401M that is a value generated on the basis of the vibration angular velocity ω_{A1s}) is multiplied by a gain K_a to be described below and is returned to the input side of the drive source 401. Specifically, a feedback control is performed on the drive source 401 so that the vibration angular velocity ω_{A1s} becomes as close to 0 as possible. Accordingly, the vibration in the robot 1 can be suppressed. In addition, the angular velocity of the drive source 401 is controlled in the feedback control.

The converter 581 converts the vibration angular velocity ω_{A1s} into the angular velocity ω_{m1s} in the first drive source 401, and outputs the angular velocity ω_{m1s} to the correction value calculator 591. This conversion can be obtained by multiplying the vibration angular velocity ω_{A1s} by the reduction ratio between the motor 401M of the first drive source 401 and the first arm 12, that is, in the joint 171.

The correction value calculator 591 multiplies the angular velocity ω_{m1s} by a gain (feedback gain) K_a that is a predetermined factor, obtains a correction value (first correction component) $K_a\omega_{m1s}$, and outputs the correction value $K_a\omega_{m1s}$ to the adder 601.

The angular velocity ω_{m1} and the correction value $K_a\omega_{m1s}$ are input to the adder 601. The adder 601 outputs an additional value of the angular velocity ω_{m1} and the correction value $K_a\omega_{m1s}$ to the subtractor 531 as the angular velocity feedback value ω_{fb} . In addition, the subsequent operation is as mentioned above.

As shown in FIG. 7, in addition to a position command P_c of the second drive source 402, detection signals are input from the second angle sensor 412 and the second (a) inertia sensor 32a, respectively, to the second drive source controller

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202. Additionally, an angular velocity $\omega A3m$ of the third arm 14 around the rotation axis O3 is input from the third drive source controller 203 to the second drive source controller 202. The second drive source controller 202 drives the second drive source 402 by a feedback control using the respective detection signals so that a rotation angle (position feedback value Pfb) of the second drive source 402 calculated from the detection signal of the second angle sensor 412 becomes the position command Pc and an angular velocity feedback value ωfb to be described below becomes an angular velocity command ωc to be described below.

That is, the position command Pc is input to the subtractor 512 of the second drive source controller 202, and the position feedback value Pfb to be described below is input from the rotation angle calculator 552. In the rotation angle calculator 552, the number of pulses input from the second angle sensor 412 is counted, and the rotation angle of the second drive source 402 according to the counted value is output to the subtractor 512 as the position feedback value Pfb. The subtractor 512 outputs a deviation (value obtained by subtracting the position feedback value Pfb from a targeted value of the rotation angle of the second drive source 402) between the position command Pc and the position feedback value Pfb to the position controller 522.

The position controller 522 performs predetermined calculation processing using the deviation input from the subtractor 512 and a proportional gain that is a predetermined factor, and calculates the targeted value of the angular velocity of the second drive source 402 according to the deviation. The position controller 522 outputs a signal showing the targeted value (command value) of the angular velocity of the second drive source 402 to the subtractor 532 as the angular velocity command (second angular velocity command) ωc . In addition, in the present embodiment, a proportional control (P control) is performed as the feedback control. However, the feedback control is not limited to this.

The angular velocity command ωc and the angular velocity feedback value ωfb to be described below are input to the subtractor 532. The subtractor 532 outputs a deviation (value obtained by subtracting the angular velocity feedback value ωfb from the targeted value of the angular velocity of the second drive source 402) between the angular velocity command ωc and the angular velocity feedback value ωfb to the angular velocity controller 542.

The angular velocity controller 542 performs predetermined calculation processing including integration, using the deviation input from the subtractor 532, a proportional gain that is a predetermined factor, an integration gain, or the like, thereby generating a driving signal (driving current) of the second drive source 402 according to the deviation and supplying the driving signal to the motor 402M via the motor driver 302. In addition, in the present embodiment, the PI control is performed as the feedback control. However, the feedback control is not limited to this.

In this way, the feedback control is performed and the driving current of the second drive source 402 is controlled so that the position feedback value Pfb is as equal to the position command Pc as possible and the angular velocity feedback value ωfb is as equal to the angular velocity command ωc as possible. In addition, since the rotation axis O2 is orthogonal to the rotation axis O1, the rotation axis is not influenced by the operation or vibration of the first arm 12, and the operation of the second drive source 402 can be controlled independently from the first drive source 401.

Next, the angular velocity feedback value ωfb in the second drive source controller 202 will be described.

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In the angular velocity calculator 562, an angular velocity $\omega m2$ of the second drive source 402 is calculated on the basis of the frequency of a pulse signal input from the second angle sensor 412, and the angular velocity $\omega m2$ is output to the adder 602.

Additionally, in the angular velocity calculator 562, the angular velocity $\omega A2m$ of the second arm 13 around the rotation axis O2 is calculated on the basis of the frequency of the pulse signal input from the second angle sensor 412, and the angular velocity $\omega A2m$ is output to the adder-subtractor 622. In addition, the angular velocity $\omega A2m$ is a value obtained by dividing the angular velocity $\omega m2$ by a reduction ratio between the motor 402M of the second drive source 402 and the second arm 13, that is, in the joint 172.

Additionally, the angular velocity of the third arm 14 around the rotation axis O2 is detected by the second (a) inertia sensor 32a. A detection signal of the second (a) inertia sensor 32a, that is, an angular velocity $\omega A3$ of the third arm 14 around the rotation axis O2 detected by the second (a) inertia sensor 32a is output to the adder-subtractor 622. In addition, since the rotation axes O2 and O3 are orthogonal to the rotation axis O1, the angular velocity of the third arm 14 around the rotation axis O2 can be easily and reliably obtained without being influenced by the operation or vibration of the first arm 12.

Additionally, an angular velocity $\omega A3m$ of the third arm 14 around the rotation axis O3 is output from the angular velocity calculator 563 of the third drive source controller 203 to be described below to the adder-subtractor 622.

The angular velocity $\omega A3$, the angular velocity $\omega A2m$, and the angular velocity $\omega A3m$ are input to the adder-subtractor 622, and the adder-subtractor 622 outputs a value $\omega A2s$ ($=\omega A3-\omega A2m-\omega A3m$) obtained by subtracting the angular velocity $\omega A2m$ and the angular velocity $\omega A3m$ from the angular velocity $\omega A3$ to the converter 582. The value $\omega A2s$ is equivalent to a vibration component (vibration angular velocity) of the total angular velocity of the second arm 13 and the third arm 14 around the rotation axis O2. Hereinafter, $\omega A2s$ is referred to as a vibration angular velocity. In the present embodiment, a feedback control is performed in which the vibration angular velocity $\omega A2s$ (in detail, an angular velocity $\omega m2s$ in the motor 402M that is a value generated on the basis of the vibration angular velocity $\omega A2s$) is multiplied by a gain Ka to be described below and is returned to the input side of the second drive source 402. Specifically, a feedback control is performed on the second drive source 402 so that the vibration angular velocity $\omega A2s$ becomes as close to 0 as possible. Accordingly, the vibration in the robot 1 can be suppressed. In addition, the angular velocity of the second drive source 402 is controlled in the feedback control.

The converter 582 converts the vibration angular velocity $\omega A2s$ into the angular velocity $\omega m2s$ in the second drive source 402, and outputs the angular velocity $\omega m2s$ to the correction value calculator 592. This conversion can be obtained by multiplying the vibration angular velocity $\omega A2s$ by the reduction ratio between the motor 402M of the second drive source 402 and the second arm 13, that is, in the joint 172.

The correction value calculator 592 multiplies the angular velocity $\omega m2s$ by a gain (feedback gain) Ka that is a predetermined factor, obtains a correction value (second correction component) $Ka \cdot \omega m2s$, and outputs the correction value $Ka \cdot \omega m2s$ to the adder 602. In addition, the gain Ka in the second drive source controller 202 and the gain Ka in the first drive source controller 201 may be the same or may be different.

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The angular velocity $\omega m2$ and the correction value $Ka \cdot \omega m2s$ are input to the adder **602**. The adder **602** outputs an additional value of the angular velocity $\omega m2$ and the correction value $Ka \cdot \omega m2s$ to the subtractor **532** as the angular velocity feedback value ωfb . In addition, the subsequent operation is as mentioned above.

As shown in FIG. 7, in addition to a position command Pc of the third drive source **403**, a detection signal is input from the third angle sensor **413** to the third drive source controller **203**. The third drive source controller **203** drives the third drive source **403** by a feedback control using the respective detection signals so that a rotation angle (position feedback value Pfb) of the third drive source **403** calculated from the detection signal of the third angle sensor **413** becomes the position command Pc and an angular velocity feedback value ωfb to be described below becomes an angular velocity command ωc to be described below.

That is, the position command Pc is input to the subtractor **513** of the third drive source controller **203**, and the position feedback value Pfb to be described below is input from the rotation angle calculator **553**. In the rotation angle calculator **553**, the number of pulses input from the third angle sensor **413** is counted, and the rotation angle of the third drive source **403** according to the counted value is output to the subtractor **513** as the position feedback value Pfb . The subtractor **513** outputs a deviation (value obtained by subtracting the position feedback value Pfb from a targeted value of the rotation angle of the third drive source **403**) between the position command Pc and the position feedback value Pfb to the position controller **523**.

The position controller **523** performs predetermined calculation processing using the deviation input from the subtractor **513**, a proportional gain that is a predetermined factor, and the like and calculates the targeted value of the angular velocity of the third drive source **403** according to the deviation. The position controller **523** outputs a signal showing the targeted value (command value) of the angular velocity of the third drive source **403** to the subtractor **533** as the angular velocity command ωc . In addition, in the present embodiment, a proportional control (P control) is performed as the feedback control. However, the feedback control is not limited to this.

Additionally, in the angular velocity calculator **563**, the angular velocity of the third drive source **403** is calculated on the basis of the frequency of a pulse signal input from the third angle sensor **413**, and the angular velocity is output to the subtractor **533** as the angular velocity feedback value ωfb .

The angular velocity command ωc and the angular velocity feedback value ωfb are input to the subtractor **533**. The subtractor **533** outputs a deviation (value obtained by subtracting the angular velocity feedback value ωfb from the targeted value of the angular velocity of the third drive source **403**) between the angular velocity command ωc and the angular velocity feedback value ωfb to the angular velocity controller **543**.

The angular velocity controller **543** performs predetermined calculation processing including integration, using the deviation input from the subtractor **533**, a proportional gain that is a predetermined factor, an integration gain, or the like, thereby generating a driving signal (driving current) of the third drive source **403** according to the deviation and supplying the driving signal to the motor **403M** via the motor driver **303**. In addition, in the present embodiment, the PI control is performed as the feedback control. However, the feedback control is not limited to this.

In this way, the feedback control is performed and the driving current of the third drive source **403** is controlled so

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that the position feedback value Pfb is as equal to the position command Pc as possible and the angular velocity feedback value ωfb is as equal to the angular velocity command ωc as possible.

In addition, since the drive source controllers **204** to **206** are the same as of the third drive source controller **203**, respectively, the description thereof will be omitted.

Here, the robot **1** has an angle detection unit that detects the angle θ (hereinafter simply referred to as "angle θ of the third arm **14**", "angle θ of the arm **14**", and "angle θ ") formed between an axis (central axis) **131** of the second arm **13**, and an axis (central axis) **141** of the third arm **14** (refer to FIG. 4), as a posture detection unit that detects the posture of the third arm **14** with the second arm **13** as a reference. In the present embodiment, the angle detection unit is constituted by the third angle sensor **413** and the control device **20**. That is, the rotation angle calculator **553** of the third drive source controller **203** of the control device **20** counts the number of pulses input from the third angle sensor **413**, obtains the rotation angle of the third drive source **403** according to the counted value, and accordingly, obtains the current angle θ of the third arm **14**.

The second drive source controller **202** (posture detection unit) adjusts (derives) a feedback gain Ka on the basis of the detection result of the angle detection unit, that is, the detected angle θ of the third arm **14**, in the aforementioned feedback control.

In this case, the second drive source controller **202** sets the feedback gain Ka to be larger as the angle θ of the third arm **14** is closer to 180° . That is, when the angle θ of the third arm **14** is within a range of being equal to or larger than 0° and smaller than 180° , the feedback gain Ka is set to be smaller as the angle θ of the third arm **14** is closer to 0° , and similarly, when the angle θ of the third arm **14** is within a range of being equal to or larger than 180° and smaller than 360° , the feedback gain Ka is set to be smaller as the angle θ of the third arm **14** is closer to 360° (0°). In addition, generally, the operation range of an arm of a robot is about 45° to 315° . However, the invention has all robots in which the operation range of the arm is within a range of 0° to 360° as targets thereof. Accordingly, in the present specification, a case where the operation range of the arm of the robot is 0° to 360° will be described.

With respect to the reason for setting the feedback gain Ka as mentioned above, first, when the angle θ of the third arm **14** is 180° , the third arm **14** is in a state (hereinafter simply referred to as an "extended state" and an "extended posture") where the third arm **14** is extended with respect to the second arm **13**. When the angle θ of the third arm **14** is 180° , the control of the robot **1** is most stable, but the inertia moment of the third arm **14** around the rotation axis $O2$ is the largest and vibration is the largest. Thus, the effect of suppressing vibration can be enhanced by setting the feedback gain Ka to be large.

Additionally, when the angle θ of the third arm **14** is 0° (360° (practically 45° or 315°), the third arm **14** is most largely curved with respect to the second arm **13**. When the angle θ of the third arm **14** is 0° (360° (practically 45° or 315°), the inertia moment of the third arm **14** around the second rotation axis $O2$ is the smallest, the control is most unstable, and vibration occurs easily. Thus, the vibration in the robot **1** can be prevented and control can be stabilized by setting the feedback gain Ka to be small. In this case, since the inertia moment is small and the vibration in the robot **1** is small from the first, vibration does not become large even if the feedback gain Ka is lowered.

In addition, when the angle θ of the third arm **14** is within a range of being equal to or larger than 0° and smaller than

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180°, the control of the robot **1** is stabilized as the angle θ of the third arm **14** is closer to 180°, the inertia moment of the third arm **14** around the rotation axis O2 is large, and vibration is large. That is, as the angle θ of the third arm **14** is closer to 0°, the control of the robot **1** is unstable, the inertia moment of the third arm **14** around the rotation axis O2 is small, and vibration is small.

Additionally, when the angle θ of the third arm **14** is within a range of being equal to or larger than 180° and smaller than 360°, the control of the robot **1** is stabilized as the angle θ of the third arm **14** is closer to 180°, the inertia moment of the third arm **14** around the rotation axis O2 is large, and vibration is large. That is, as the angle θ of the third arm **14** is closer to 360°, the control of the robot **1** is unstable, the inertia moment of the third arm **14** around the rotation axis O2 is small, and vibration is small.

In this way, in the robot **1**, by adjusting the feedback gain Ka according to the posture of the third arm **14**, vibration can be reliably suppressed while stabilizing control. That is, the compatibility between the suppression of vibration and the stability of control can be achieved.

In addition, the feedback gains Ka in the drive source controllers **201** and **202** are preferably set to be smaller than 1, respectively.

If the reason is representatively described in the first drive source controller **201** and the feedback gain Ka is set to 1, the angular velocity ω_{m1} of the first drive source **401** detected and obtained by the first angle sensor **411**, and the component of the angular velocity of the first drive source **401** detected and obtained by the first angle sensor **411** in the correction value $Ka \cdot \omega_{m1}$ is offset in the adder **601**. Accordingly, the component of the angular velocity of the first drive source **401** detected and obtained by the first angle sensor **411** in the angular velocity feedback value ω_{fb} becomes 0, and control becomes unstable.

Additionally, if the feedback gain Ka is set to be larger than 1, the component of the angular velocity of the first drive source **401** detected and obtained by the first angle sensor **411** in the angular velocity feedback value ω_{fb} becomes negative, the component of the angular velocity is positively fed back, and control becomes unstable.

In addition, for example, a correction value calculator (not shown) that multiplies the angular velocity ω_{m1} of the first drive source **401** detected and obtained by the first angle sensor **411** by a gain (feedback gain) Kb that is a predetermined factor, obtains a correction value $Kb \cdot \omega_{m1}$, and outputs the correction value $Kb \cdot \omega_{m1}$ to the adder **601** may be provided between the angular velocity calculator **561** and the adder **601**. In this case, from the above reason, the feedback gain Ka is preferably set to be smaller than the feedback gain Kb. In this case, the feedback gain Ka can be set to be equal to or larger than 1 depending on the value of the feedback gain Kb. In addition, a case where the correction value calculator is not provided between the angular velocity calculator **561** and an adder **601** with respect to the value of a feedback gain Ka will be representatively described below.

Next, adjustment of the feedback gain Ka in the second drive source controller **202** will be described.

In addition, cases where the feedback gains Ka are set in a case where the angle θ of the third arm **14** is smaller than θ_1 , a case where the angle is equal to or larger than θ_1 and smaller than θ_2 , a case where the angle is equal to or larger than θ_2 and smaller than θ_3 , a case where the angle is equal to or larger than θ_3 and smaller than θ_4 , and a case where the angle is equal to or larger than θ_4 ($\theta_1 < \theta_2 < \theta_3 < \theta_4$) will be representatively described here, respectively.

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As shown in FIG. **11**, first, the second drive source controller **202** detects the rotation angle of the third drive source **403** by the third angle sensor **413** via the third drive source controller **203** (Step S101). That is, the third drive source controller **203** counts the number of pulses input from the third angle sensor **413** and obtains the rotation angle of the third drive source **403** according to the counted value, and the second drive source controller **202** acquires information on the rotation angle of the third drive source **403**.

Next, the angle θ of the third arm **14** is obtained on the basis of the rotation angle of the third drive source **403** (Step S102).

Next, it is determined whether or not the angle θ of the third arm **14** is smaller than θ_1 (Step S103). Then, when the angle θ of the third arm **14** is smaller than θ_1 , the feedback gain Ka is set to Ka1 (Step S104). In addition, since the operation range of the third arm **14** is set to, for example, 45° to 315° in the present embodiment, it is determined in Step S103 whether or not the angle θ of the third arm **14** is equal to or larger than 45° and smaller than θ_1 .

Additionally, when the angle θ of the third arm **14** is not smaller than θ_1 in Step S103, it is determined whether or not the angle θ of the third arm **14** is equal to or larger than θ_1 and smaller than θ_2 (Step S105), and when the angle θ of the third arm **14** is equal to or larger than θ_1 and smaller than θ_2 in Step S105, the feedback gain Ka is set to Ka2 (Step S106).

Additionally, when the angle θ of the third arm **14** is not equal to or larger than θ_1 and smaller than θ_2 in Step S105, it is determined whether or not the angle θ of the third arm **14** is equal to or larger than θ_2 and smaller than θ_3 (Step S107), and when the angle θ of the third arm **14** is equal to or larger than θ_2 and smaller than θ_3 in Step S107, the feedback gain Ka is set to Ka3 (Step S108).

Additionally, when the angle θ of the third arm **14** is not equal to or larger than θ_2 and smaller than θ_3 in Step S107, it is determined whether or not the angle θ of the third arm **14** is equal to or larger than θ_3 and smaller than θ_4 (Step S109), and when the angle θ of the third arm **14** is equal to or larger than θ_3 and smaller than θ_4 in Step S109, the feedback gain Ka is set to Ka4 (Step S110).

Additionally, when the angle θ of the third arm **14** is not equal to or larger than θ_3 and smaller than θ_4 in Step S109, it is determined whether or not the angle θ of the third arm **14** is equal to or larger than θ_4 (Step S111), and when the angle θ of the third arm **14** is equal to or larger than θ_4 in Step S111, the feedback gain Ka is set to Ka5 (Step S112). In addition, as mentioned above, since the operation range of the third arm **14** is set to, for example, 45° to 315° in the present embodiment, it is determined in Step S111 whether or not the angle θ of the third arm **14** is equal to or larger than θ_4 and equal to or smaller than 315°.

The above respective steps are executed for every control cycle, and return to Step S101 is made again after Steps S104, S106, S108, S110, and S112. Then, Step S101 and the subsequent steps are executed.

In addition, $Ka1 < Ka2 < Ka3 < Ka4 < Ka5$ is established. Additionally, Ka1 and Ka5 may be the same or different. Additionally, Ka2 and Ka4 may be the same or different.

Here, although θ_1 is appropriately set according to terms and conditions and is not particularly limited, θ_1 is preferably from 70° to 110° and more preferably from 90° to 100°. As one example, θ_1 is set to, for example, 90°.

Additionally, although θ_2 is appropriately set according to terms and conditions and is not particularly limited, θ_2 is preferably from 115° to 155° and more preferably from 125° to 145°. As one example, θ_2 is set to, for example, 135°.

Here, although θ_3 is appropriately set according to terms and conditions and is not particularly limited, θ_3 is preferably

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from 205° to 245° and more preferably from 215° to 235°. As one example, θ_3 is set to, for example, 225°.

Additionally, although θ_4 is appropriately set according to terms and conditions and is not particularly limited, θ_4 is preferably from 250° to 290° and more preferably from 260° to 280°. As one example, θ_4 is set to, for example, 270°.

Accordingly, the vibration in the robot can be more reliably suppressed while stabilizing control.

When the angle θ is smaller than θ_1 , the feedback gain Ka is set to Ka1 as mentioned above. Ka1 is preferably from 0 to 0.3 and more preferably from 0 to 0.2.

Additionally, when the angle θ is equal to or larger than θ_1 and smaller than θ_2 , the feedback gain Ka is set to Ka2 as mentioned above. Ka2 is preferably from 0.1 to 0.5 and more preferably from 0.2 to 0.4.

Additionally, when the angle θ is equal to or larger than θ_2 and smaller than θ_3 , the feedback gain Ka is set to Ka3 as mentioned above. Ka3 is preferably from 0.3 to 0.7 and more preferably from 0.3 to 0.6.

Additionally, when the angle θ is equal to or larger than θ_3 and smaller than θ_4 , the feedback gain Ka is set to Ka4 as mentioned above. Ka4 is preferably from 0.1 to 0.5 and more preferably from 0.2 to 0.4.

Additionally, when the angle θ is equal to or larger than θ_4 , the feedback gain Ka is set to Ka5 as mentioned above. Ka5 is preferably from 0 to 0.3 and more preferably from 0 to 0.2.

Accordingly, the vibration in the robot can be more reliably suppressed while stabilizing control.

As described above, according to the robot 1, the vibration in the robot 1 can be easily and reliably suppressed.

First, in the control of the robot 1, huge calculation is unnecessary, and thereby, response speed in the control of the robot 1 can be increased, and the configuration of the control device 20 can be simplified.

Additionally, in the control of the robot 1, calculation in which a singular point is present is unnecessary. Thus, the control of the robot 1 can be reliably performed, and thereby, vibration can be reliably suppressed.

Additionally, since the control of suppressing vibration is performed on the second drive source 402 that drives the second arm 13, using the detection result of the second (a) inertia sensor 32a installed at the third arm 14 on the tip side where a larger vibration than the second arm 13 is generated, the effect of suppressing the vibration in the robot 1 can be enhanced. Additionally, the effect of suppressing the vibration in the robot 1 can be enhanced by controlling the operation of the second drive source 402 that rotates the second arm 13 closer to the base end side than the third arm 14.

Additionally, since the inertia sensors 31 and 32a are installed at the first arm 12 and the third arm 14, respectively, and the first rotation axis O1 for the rotation of the first arm 12, the second rotation axis O2 for the rotation of the second arm 13, and the third rotation axis O3 for the rotation of the third arm 14 are made orthogonal to each other, the angular velocities of the first arm 12 and the third arm 14 can be detected as simple rotational components in which these angular velocities are not mixed. Hence, since control is performed by the calculation using these angular velocities, the vibration in the robot 1 can be more easily, accurately, and reliably suppressed.

In addition, since the first rotation axis O1 for the rotation of the first arm 12, the second rotation axis O2 for the rotation of the second arm 13, and the third rotation axis O3 for the rotation of the third arm 14 are made orthogonal to each other, the angular velocities of the first arm 12 and the third arm 14 can be detected as simple rotational components in which these angular velocities are not mixed. Since the rotational

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components with no mixture of these angular velocities are multiplied by feedback gains, respectively, the respective rotational components can be corrected with high precision.

Additionally, by adjusting the feedback gain Ka according to the posture of the third arm 14 in this way, vibration can be reliably suppressed while stabilizing control.

In addition, in the present embodiment, the angle θ of the third arm 14 is divided into five ranges. However, the invention is not limited to this, and the angle θ may be divided into, for example, two, three, four, or six or more ranges. Additionally, continuous feedback gain Ka may be made correspond to an angle θ that is not gradual but continuous.

Additionally, other specific examples of Ka1 to Ka5 are shown below.

The specific examples are obtained in consideration of a case where the vibration angular velocity ω_{A2s} has an opposite phase. When the vibration angular velocity ω_{A2s} has an opposite phase, the vibration angular velocity can be converted into a normal phase by making the feedback gain Ka negative.

First, Ka1 is preferably from -0.2 to 0.3 and more preferably from -0.1 to 0.1.

Additionally, Ka2 is preferably from 0.1 to 0.4 and more preferably from 0.1 to 0.3.

Additionally, Ka3 is preferably from 0.3 to 0.7 and more preferably from 0.3 to 0.6.

Additionally, Ka4 is preferably from 0.1 to 0.4 and more preferably from 0.1 to 0.3.

Additionally, Ka5 is preferably from -0.2 to 0.3 and more preferably from -0.1 to 0.1.

Second Embodiment

A second embodiment will be described below mainly regarding the differences from the aforementioned first embodiment, and the description of the same matters will be omitted.

In the robot 1 of the second embodiment, the second drive source controller 202 adjusts the feedback gain Ka on the basis of tip load mass in the tip portion of the robot 1, that is, the tip portion of the wrist 16, in the feedback control.

This tip load mass is the total mass of the manipulator mounted on the tip portion of the wrist 16 that is an arm closest to the tip side and an object to be gripped by the manipulator. That is, the tip load mass is the total mass of the manipulator and the object gripped by the manipulator when the manipulator is gripping the object and is the mass of the manipulator when the manipulator is not gripping the object.

In the present embodiment, both the mass of the manipulator and the mass of the object gripped by the manipulator are already known, and the masses are stored in advance in a storage (not shown) of the control device 20. Additionally, the control device 20 grasps whether or not the manipulator is gripping the object. Accordingly, the control device 20 always grasps the tip load mass of the robot 1. In addition, the object to be gripped by the manipulator may be a plurality of kinds of objects having different masses.

Additionally, the second drive source controller 202 sets the feedback gain Ka to be smaller as the tip load mass becomes larger.

This is because, as the tip load mass is larger, the vibration in the robot 1 is smaller but the control is unstable and vibration occurs easily. Thus, by setting the feedback gain Ka to be small, the vibration in the robot 1 can be prevented, and the control can be stabilized.

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In other words, since the control of the robot 1 is stable as the tip load mass is smaller, the effect of suppressing vibration can be enhanced by setting the feedback gain K_a to be large.

Next, adjustment of the feedback gain K_a will be described.

Additionally, cases where the feedback gains K_a are set in combinations of each of a case where the angle θ of the third arm 14 is smaller than θ_1 , a case where the angle is equal to or larger than θ_1 and smaller than θ_2 , a case where the angle is equal to or larger than θ_2 and smaller than θ_3 , a case where the angle is equal to or larger than θ_3 and smaller than θ_4 , and a case where the angle is equal to or larger than θ_4 ($\theta_1 < \theta_2 < \theta_3 < \theta_4$) and each of a case where the tip load mass is 1 kg, a case where the tip load mass is 3 kg, and a case where the tip load mass is 5 kg will be representatively described here, respectively.

First, when the angle θ is smaller than θ_1 and the tip load mass is 1 kg, the feedback gain K_a is preferably from 0 to 0.4 and more preferably from 0.1 to 0.3.

Additionally, when the angle θ is smaller than θ_1 and the tip load mass is 3 kg, the feedback gain K_a is preferably from 0 to 0.3 and more preferably from 0 to 0.2.

Additionally, when the angle θ is smaller than θ_1 and the tip load mass is 5 kg, the feedback gain K_a is preferably from -0.2 to 0.2 and more preferably from -0.1 to 0 .

Additionally, when the angle θ is equal to or larger than θ_1 and smaller than θ_2 and the tip load mass is 1 kg, the feedback gain K_a is preferably from 0.1 to 0.5 and more preferably from 0.2 to 0.4 .

Additionally, when the angle θ is equal to or larger than θ_1 and smaller than θ_2 and the tip load mass is 3 kg, the feedback gain K_a is preferably from 0.1 to 0.5 and more preferably from 0.2 to 0.3 .

Additionally, when the angle θ is equal to or larger than θ_1 and smaller than θ_2 and the tip load mass is 5 kg, the feedback gain K_a is preferably from 0 to 0.4 and more preferably from 0 to 0.3 .

Additionally, when the angle θ is equal to or larger than θ_2 and smaller than θ_3 and the tip load mass is 1 kg, the feedback gain K_a is preferably from 0.3 to 0.7 and more preferably from 0.4 to 0.6 .

Additionally, when the angle θ is equal to or larger than θ_2 and smaller than θ_3 and the tip load mass is 3 kg, the feedback gain K_a is preferably from 0.3 to 0.7 and more preferably from 0.3 to 0.6 .

Additionally, when the angle θ is equal to or larger than θ_2 and smaller than θ_3 and the tip load mass is 5 kg, the feedback gain K_a is preferably from 0.3 to 0.7 and more preferably from 0.3 to 0.6 .

Additionally, when the angle θ is equal to or larger than θ_3 and smaller than θ_4 and the tip load mass is 1 kg, the feedback gain K_a is preferably from 0.1 to 0.5 and more preferably from 0.2 to 0.4 .

Additionally, when the angle θ is equal to or larger than θ_3 and smaller than θ_4 and the tip load mass is 3 kg, the feedback gain K_a is preferably from 0.1 to 0.5 and more preferably from 0.2 to 0.3 .

Additionally, when the angle θ is equal to or larger than θ_3 and smaller than θ_4 and the tip load mass is 5 kg, the feedback gain K_a is preferably from 0 to 0.4 and more preferably from 0 to 0.3 .

Additionally, when the angle θ is equal to or larger than θ_4 and the tip load mass is 1 kg, the feedback gain K_a is preferably from 0 to 0.4 and more preferably from 0.1 to 0.3 .

Additionally, when the angle θ is equal to or larger than θ_4 and the tip load mass is 3 kg, the feedback gain K_a is preferably from 0 to 0.3 and more preferably from 0 to 0.2 .

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Additionally, when the angle θ is equal to or larger than θ_4 and the tip load mass is 5 kg, the feedback gain K_a is preferably from -0.2 to 0.2 and more preferably from -0.1 to 0 .

Accordingly, the vibration in the robot can be more reliably suppressed while stabilizing control.

According to the robot 1, the same effects as the aforementioned first embodiment are obtained.

In the robot 1, by adjusting the feedback gain K_a according to the posture of the third arm 14 and the tip load mass in this way, vibration can be more reliably suppressed while stabilizing control.

Third Embodiment

FIG. 12 is a schematic view showing a third embodiment of the robot of the invention. FIGS. 13 and 14 are block diagrams of main portions of the robot shown in FIG. 12, respectively. FIG. 15 is a flowchart showing the control operation of the control device of the robot shown in FIG. 1.

In addition, in the following, for the convenience of description, the upper side in FIG. 12 is referred to as "upper" and "upside" and the lower side is referred to as "lower" and "downside". Additionally, the base side in FIG. 12 is referred to as a "base end", and the opposite side is referred to as a "tip". Additionally, the rotation axes O_2 and O_3 are shown in an exaggerated manner in FIG. 12, respectively. Additionally, inertia sensors 31 and 32b are shown outside arms 12 and 13 in FIG. 12, respectively, in order to clarify the presence of the sensors.

The third embodiment will be described below mainly regarding differences from the aforementioned first embodiment, and the description of the same matters will be omitted.

As shown in FIG. 12, in the robot 1 of the third embodiment, an inertia sensor is not installed at the third arm 14, and a second (b) inertia sensor 32b is installed at the second arm 13. The second (b) inertia sensor 32b detects the angular velocity of the second arm 13 around the rotation axis O_2 . Although the installation position of the second (b) inertia sensor 32b at the second arm 13 is not particularly limited, a tip portion of the second arm 13 is preferable. In the present embodiment, the second (b) inertia sensor 32b is installed at the tip portion inside the second arm 13. Since the vibration in the second arm 13 becomes the maximum at the tip portion of the second arm, this can more reliably suppress the vibration in the robot 1. In addition, it is obvious that the second (b) inertia sensor 32b may be installed at a base end portion of the second arm 13.

Additionally, the second (b) inertia sensor 32b is not particularly limited, and in the present embodiment, for example, a gyroscope sensor or the like can be used.

Here, in the robot 1, in order to suppress the vibration in the first arm 12 and the second arm 13, the first inertia sensor 31 and the second (b) inertia sensor 32b are installed at both the first arm 12 and the second arm 13 as mentioned above, and the operation of the drive sources 401 and 402 is controlled on the basis of detection results of the first inertia sensor 31 and the second (b) inertia sensor 32b. Accordingly, the vibration in the first arm 12 and the second arm 13 can be reliably suppressed, and thereby, the vibration in the whole robot 1 can be reliably suppressed.

Additionally, in the robot 1, the second drive source controller 202 of the control device 20 is different from that of the first embodiment.

As shown in FIG. 13, the second drive source controller 202 has a subtractor 517, a position controller 527, a subtractor 537, an angular velocity controller 547, a rotation angle

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calculator 557, an angular velocity calculator 567, a subtractor 577, a converter 587, a correction value calculator 597, and an adder 607.

Additionally, as shown in FIG. 14, the third drive source controller 203 has a subtractor 518, a position controller 528, a subtractor 538, an angular velocity controller 548, a rotation angle calculator 558, and an angular velocity calculator 568. The second drive source controller 202 will be described below.

As shown in FIG. 13, in addition to a position command P_c of the second drive source 402, detection signals are input from the second angle sensor 412 and the second (b) inertia sensor 32b, respectively, to the second drive source controller 202. The second drive source controller 202 drives the second drive source 402 by a feedback control using the respective detection signals so that a rotation angle (position feedback value P_{fb}) of the second drive source 402 calculated from the detection signal of the second angle sensor 412 becomes the position command P_c and an angular velocity feedback value ω_{fb} to be described below becomes an angular velocity command ω_c to be described below.

That is, the position command P_c is input to the subtractor 517 of the second drive source controller 202, and the position feedback value P_{fb} to be described below is input from the rotation angle calculator 557. In the rotation angle calculator 557, the number of pulses input from the second angle sensor 412 is counted, and the rotation angle of the second drive source 402 according to the counted value is output to the subtractor 517 as the position feedback value P_{fb} . The subtractor 517 outputs a deviation (value obtained by subtracting the position feedback value P_{fb} from a targeted value of the rotation angle of the second drive source 402) between the position command P_c and the position feedback value P_{fb} to the position controller 527.

The position controller 527 performs predetermined calculation processing using the deviation input from the subtractor 517 and a proportional gain that is a predetermined factor, and calculates the targeted value of the angular velocity of the second drive source 402 according to the deviation. The position controller 527 outputs a signal showing the targeted value (command value) of the angular velocity of the second drive source 402 to the subtractor 537 as the angular velocity command (second angular velocity command) ω_c . In addition, in the present embodiment, a proportional control (P control) is performed as the feedback control. However, the feedback control is not limited to this.

The angular velocity command ω_c and the angular velocity feedback value ω_{fb} to be described below are input to the subtractor 537. The subtractor 537 outputs a deviation (value obtained by subtracting the angular velocity feedback value ω_{fb} from the targeted value of the angular velocity of the second drive source 402) between the angular velocity command ω_c and the angular velocity feedback value ω_{fb} to the angular velocity controller 547.

The angular velocity controller 547 performs predetermined calculation processing including integration, using the deviation input from the subtractor 537, a proportional gain that is a predetermined factor, an integration gain, or the like, thereby generating a driving signal (driving current) of the second drive source 402 according to the deviation and supplying the driving signal to the motor 402M via the motor driver 302. In addition, in the present embodiment, the PI control is performed as the feedback control. However, the feedback control is not limited to this.

In this way, the feedback control is performed and the driving current of the second drive source 402 is controlled so that the position feedback value P_{fb} is as equal to the position

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command P_c as possible and the angular velocity feedback value ω_{fb} is as equal to the angular velocity command ω_c as possible. In addition, since the rotation axis O2 is orthogonal to the rotation axis O1, the rotation axis is not influenced by the operation or vibration of the first arm 12, and the operation of the second drive source 402 can be controlled independently from the first drive source 401.

Next, the angular velocity feedback value ω_{fb} in the second drive source controller 202 will be described.

In an angular velocity calculator 567, an angular velocity ω_{m2} of the second drive source 402 is calculated on the basis of the frequency of a pulse signal input from the second angle sensor 412, and the angular velocity ω_{m2} is output to an adder 602.

Additionally, in the angular velocity calculator 567, an angular velocity ω_{A2m} of the second arm 13 around the rotation axis O2 is calculated on the basis of the frequency of the pulse signal input from the second angle sensor 412, and the angular velocity ω_{A2m} is output to the subtractor 577. In addition, the angular velocity ω_{A2m} is a value obtained by dividing the angular velocity ω_{m2} by a reduction ratio between the motor 402M of the second drive source 402 and the second arm 13, that is, in the joint 172.

Additionally, the second (b) inertia sensor 32b detects the angular velocity of the second arm 13 around the rotation axis O2. A detection signal of the second (b) inertia sensor 32b, that is, an angular velocity ω_{A2} of the second arm 13 around the rotation axis O2 detected by the second (b) inertia sensor 32b is output to the subtractor 577. In addition, since the rotation axis O2 is orthogonal to the rotation axis θ_1 , the angular velocity of the second arm 13 around the rotation axis O2 can be easily and reliably obtained without being influenced by the operation or vibration of the first arm 12.

The angular velocity ω_{A2} and the angular velocity ω_{A2m} are input to the subtractor 577, and the subtractor 577 outputs a value ω_{A2s} ($=\omega_{A2}-\omega_{A2m}$) obtained by subtracting the angular velocity ω_{A2m} from the angular velocity ω_{A2} to the converter 587. The value ω_{A2s} is equivalent to a vibration component (vibration angular velocity) of the angular velocity of the second arm 13 around the rotation axis O2. Hereinafter, ω_{A2s} is referred to as a vibration angular velocity. In the present embodiment, a feedback control is performed in which the vibration angular velocity ω_{A2s} (in detail, an angular velocity ω_{m2s} in the motor 402M that is a value generated on the basis of the vibration angular velocity ω_{A2s}) is multiplied by a gain K_a to be described below and is returned to the input side of the second drive source 402. Specifically, a feedback control is performed on the second drive source 402 so that the vibration angular velocity ω_{A2s} becomes as close to 0 as possible. Accordingly, the vibration in the robot 1 can be suppressed. In addition, the angular velocity of the second drive source 402 is controlled in the feedback control.

The converter 587 converts the vibration angular velocity ω_{A2s} into the angular velocity ω_{m2s} in the second drive source 402, and outputs the angular velocity ω_{m2s} to the correction value calculator 597. This conversion can be obtained by multiplying the vibration angular velocity ω_{A2s} by the reduction ratio between the motor 402M of the second drive source 402 and the second arm 13, that is, in the joint 172.

The correction value calculator 597 multiplies the angular velocity ω_{m2s} by a gain (feedback gain) K_a that is a predetermined factor, obtains a correction value (second correction component) $K_a \cdot \omega_{m2s}$, and outputs the correction value $K_a \cdot \omega_{m2s}$ to the adder 607. In addition, the gain K_a in the

second drive source controller **202** and the gain K_a in the first drive source controller **201** may be the same or may be different.

The angular velocity $\omega m2$ and the correction value $K_a \cdot \omega m2s$ are input to the adder **607**. The adder **607** outputs an additional value of the angular velocity $\omega m2$ and the correction value $K_a \cdot \omega m2s$ to the subtractor **537** as the angular velocity feedback value ωfb . In addition, the subsequent operation is the same as that of the first embodiment.

Since the third drive source controller **203** shown in FIG. **14** is the same as that of the first embodiment except that calculation and output of the angular velocity $\omega A3m$ is not performed, the description thereof is omitted.

Here, the robot **1** has an angle detection unit that detects the angle θ (hereinafter simply referred to as “angle θ of the second arm **13**”, “angle θ of the arm **13**”, and “angle θ ”) formed between an axis (central axis) **121** (rotation axis **O1**) of the first arm **12**, and an axis (central axis) **131** of the second arm **13** (refer to FIG. **12**), as a posture detection unit that detects the posture of the second arm **13** with the first arm **12** as a reference. In the present embodiment, the angle detection unit is constituted by the second angle sensor **412** and the control device **20**. That is, the rotation angle calculator **557** of the second drive source controller **202** of the control device **20** counts the number of pulses input from the second angle sensor **412**, obtains the rotation angle of the second drive source **402** according to the counted value, and thereby, obtains the current angle θ of the second arm **13**.

The first drive source controller **201** (posture detection unit) adjusts (derives) a feedback gain K_a on the basis of the detection result of the angle detection unit, that is, the detected angle θ of the second arm **13**, in the aforementioned feedback control.

In this case, the first drive source controller **201** sets the feedback gain K_a to be larger as the angle θ of the second arm **13** is closer to 90° when the angle θ of the second arm **13** is within a range of being equal to or larger than 0° and smaller than 180° . That is, when the angle θ of the second arm **13** is within a range of being equal to or larger than 0° and smaller than 90° , the feedback gain K_a is set to be smaller as the angle θ of the second arm **13** is closer to 0° , and similarly, when the angle θ of the second arm **13** is within a range of being equal to or larger than 90° and smaller than 180° , the feedback gain K_a is set to be smaller as the angle θ of the second arm **13** is closer to 180° .

Additionally, when the angle θ of the second arm **13** is within a range of being equal to or larger than 180° and smaller than 360° , the feedback gain K_a is set to be larger as the angle θ of the second arm **13** is closer to 270° . That is, when the angle θ of the second arm **13** is within a range of being equal to or larger than 180° and smaller than 270° , the feedback gain K_a is set to be smaller as the angle θ of the second arm **13** is closer to 180° , and similarly, when the angle θ of the second arm **13** is within a range of being equal to or larger than 270° and smaller than 360° , the feedback gain K_a is set to be smaller as the angle θ of the second arm **13** is closer to 360° (0°).

First, this is because, when the angle θ of the second arm **13** is 90° or 270° , the control of the robot **1** is most stable, but the inertia moment of the second arm **13** around the rotation axis **O1** is the largest and vibration is the largest. Thus, the effect of suppressing vibration can be enhanced by setting the feedback gain K_a to be large.

Additionally, when the angle θ of the second arm **13** is 0° or 180° , the inertia moment of the second arm **13** around the first rotation axis **O1** is the smallest, the control is most unstable, and vibration occurs easily. Thus, the vibration in

the robot **1** can be prevented and control can be stabilized by setting the feedback gain K_a to be small. In this case, since the inertia moment is small and the vibration in the robot **1** is small from the first, vibration does not become large even if the feedback gain K_a is lowered.

In addition, when the angle θ of the second arm **13** is within a range of being equal to or larger than 0° and smaller than 90° , the control of the robot **1** is stabilized as the angle θ of the second arm **13** is closer to 90° , the inertia moment of the second arm **13** around the rotation axis **O1** is large, and vibration is large. That is, as the angle θ of the second arm **13** is closer to 0° , the control of the robot **1** is unstable, the inertia moment of the second arm **13** around the rotation axis **O1** is small, and vibration is small.

Additionally, when the angle θ of the second arm **13** is within a range of being equal to or larger than 90° and smaller than 180° , the control of the robot **1** is stabilized as the angle θ of the second arm **13** is closer to 90° , the inertia moment of the second arm **13** around the rotation axis **O1** is large, and vibration is large. That is, as the angle θ of the second arm **13** is closer to 180° , the control of the robot **1** is unstable, the inertia moment of the second arm **13** around the rotation axis **O1** is small, and vibration is small.

Additionally, when the angle θ of the second arm **13** is within a range of being equal to or larger than 180° and smaller than 270° , the control of the robot **1** is stabilized as the angle θ of the second arm **13** is closer to 270° , the inertia moment of the second arm **13** around the rotation axis **O1** is large, and vibration is large. That is, as the angle θ of the second arm **13** is closer to 180° , the control of the robot **1** is unstable, the inertia moment of the second arm **13** around the rotation axis **O1** is small, and vibration is small.

Additionally, when the angle θ of the second arm **13** is within a range of being equal to or larger than 270° and smaller than 360° , the control of the robot **1** is stabilized as the angle θ of the second arm **13** is closer to 270° , the inertia moment of the second arm **13** around the rotation axis **O1** is large, and vibration is large. That is, as the angle θ of the second arm **13** is closer to 360° , the control of the robot **1** is unstable, the inertia moment of the second arm **13** around the rotation axis **O1** is small, and vibration is small.

In this way, in the robot **1**, by adjusting the feedback gain K_a according to the posture of the second arm **13**, vibration can be reliably suppressed while stabilizing control. That is, the compatibility between the suppression of vibration and the stability of control can be achieved.

Next, adjustment of the feedback gain K_a in the first drive source controller **201** will be described.

In addition, cases where the feedback gains K_a are set, respectively, in a case where the angle θ of the second arm **13**, a case where the angle is smaller than $\theta 11$, a case where the angle is equal to or larger than $\theta 11$ and smaller than $\theta 12$, and a case where the angle is equal to or larger than $\theta 12$ ($\theta 11 < \theta 12$) within a range in which the angle θ of the second arm **13** is equal to or larger than 0° and smaller than 180° , and similarly, cases where the feedback gains K_a are set, respectively, in a case where the angle θ of the second arm **13** is smaller than $\theta 21$, a case where the angle is equal to or larger than $\theta 21$ and smaller than $\theta 22$, and a case where the angle is equal to or larger than $\theta 22$ ($\theta 21 < \theta 22$) within a range in which the angle θ of the second arm **13** is equal to or larger than 180° and smaller than 360° will be representatively described here.

As shown in FIG. **15**, first, the second drive source controller **202** detects the rotation angle of the second drive source **402** by the second angle sensor **412** (Step **S201**). That is, the number of pulses input from the second angle sensor **412** is

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counted, and the rotation angle of the second drive source 402 according to the counted value is obtained.

Next, the angle θ of the second arm 13 is obtained on the basis of the rotation angle of the second drive source 402 (Step S202).

Additionally, it is determined whether or not the angle θ of the second arm 13 is smaller than 180° (Step S203). Then, when the angle θ of the second arm 13 is smaller than 180° , it is determined whether or not the angle θ of the second arm 13 is smaller than θ_{11} (Step S204), and when the angle θ of the second arm 13 is smaller than θ_{11} , the feedback gain Ka is set to Ka11 (Step S205). In addition, since the operation range of the second arm 13 is set to, for example, 50° to 310° in the present embodiment, it is determined in Step S204 whether or not the angle θ of the second arm 13 is equal to or larger than 50° and smaller than θ_{11} .

Additionally, when the angle θ of the second arm 13 is not smaller than θ_{11} in Step S204, it is determined whether or not the angle θ of the second arm 13 is equal to or larger than θ_{11} and smaller than θ_{12} (Step S206), and when the angle θ of the second arm 13 is equal to or larger than θ_{11} and smaller than θ_{12} in Step S204, the feedback gain Ka is set to Ka12 (Step S207).

Additionally, when the angle θ of the second arm 13 is not equal to or larger than θ_{11} and smaller than θ_{12} in Step S206, it is determined whether or not the angle θ of the second arm 13 is equal to or larger than θ_{12} (Step S208), and when the angle θ of the second arm 13 is equal to or larger than θ_{12} in Step S208, the feedback gain Ka is set to Ka13 (Step S209).

Additionally, when the angle θ of the second arm 13 is not smaller than 180° in Step S204, it is determined whether or not the angle θ of the second arm 13 is smaller than θ_{21} (Step S210), and when the angle θ of the second arm 13 is smaller than θ_{21} in Step S210, the feedback gain Ka is set to Ka21 (Step S211).

Additionally, when the angle θ of the second arm 13 is not smaller than θ_{21} in Step S210, it is determined whether or not the angle θ of the second arm 13 is equal to or larger than θ_{21} and smaller than θ_{22} (Step S212), and when the angle θ of the second arm 13 is equal to or larger than θ_{21} and smaller than θ_{22} in Step S212, the feedback gain Ka is set to Ka22 (Step S213).

Additionally, when the angle θ of the second arm 23 is not equal to or larger than θ_{21} and smaller than θ_{22} in Step S212, it is determined whether or not the angle θ of the second arm 13 is equal to or larger than θ_{22} (Step S214), and when the angle θ of the second arm 13 is equal to or larger than θ_{22} in Step S214, the feedback gain Ka is set to Ka23 (Step S215). In addition, as mentioned above, since the operation range of the second arm 13 is set to, for example, 50° to 310° in the present embodiment, it is determined in Step S214 whether or not the angle θ of the second arm 13 is equal to or larger than θ_{22} and equal to or smaller than 310° .

The above respective steps are executed for every control cycle, and return to Step S201 is made again after Steps S205, S207, S209, S211, S213, and S215. Then, Step S201 and the subsequent steps are executed.

In addition, $Ka_{11} > Ka_{12} > Ka_{13}$ and $Ka_{21} < Ka_{22} < Ka_{23}$ are established. Additionally, Ka11 and Ka23 may be the same or different. Additionally, Ka12 and Ka22 may be the same or different. Additionally, Ka13 and Ka21 may be the same or different.

Here, although θ_{11} is appropriately set according to terms and conditions and is not particularly limited, θ_{11} is preferably from 115° to 155° and more preferably from 125° to 145° . As one example, θ_{11} is set to, for example, 130° .

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Additionally, although θ_{12} is appropriately set according to terms and conditions and is not particularly limited, θ_{12} is preferably from 145° to 175° and more preferably from 155° to 165° . As one example, θ_{12} is set to, for example, 160° .

Additionally, although θ_{21} is appropriately set according to terms and conditions and is not particularly limited, θ_{21} is preferably from 185° to 215° and more preferably from 195° to 205° . As one example, θ_{21} is set to, for example, 200° .

Additionally, although θ_{22} is appropriately set according to terms and conditions and is not particularly limited, θ_{22} is preferably from 205° to 245° and more preferably from 215° to 235° . As one example, θ_{22} is set to, for example, 230° .

Accordingly, the vibration in the robot can be more reliably suppressed while stabilizing control.

When the angle θ is smaller than θ_{11} , the feedback gain Ka is set to Ka11 as mentioned above. Ka11 is preferably from 0.2 to 0.7 and more preferably from 0.4 to 0.5.

Additionally, when the angle θ is equal to or larger than θ_{11} and smaller than θ_{12} , the feedback gain Ka is set to Ka12 as mentioned above. Ka12 is preferably from 0.1 to 0.4 and more preferably from 0.2 to 0.4.

Additionally, when the angle θ is equal to or larger than θ_{12} , the feedback gain Ka is set to Ka13 as mentioned above. Ka13 is preferably from 0 to 0.3 and more preferably from 0.1 to 0.2.

Additionally, when the angle θ is smaller than θ_{21} , the feedback gain Ka is set to Ka21 as mentioned above. Ka21 is preferably from 0 to 0.3 and more preferably from 0.1 to 0.2.

Additionally, when the angle θ is equal to or larger than θ_{21} and smaller than θ_{22} , the feedback gain Ka is set to Ka22 as mentioned above. Ka22 is preferably from 0.1 to 0.4 and more preferably from 0.2 to 0.4.

Additionally, when the angle θ is equal to or larger than θ_{22} , the feedback gain Ka is set to Ka23 as mentioned above. Ka23 is preferably from 0.2 to 0.7 and more preferably from 0.4 to 0.5.

Accordingly, the vibration in the robot can be more reliably suppressed while stabilizing control.

According to the robot 1, the same effects as the aforementioned first embodiment are obtained.

In addition, in the present embodiment, the angle θ of the second arm 13 is divided into six ranges. However, the invention is not limited to this, and the angle θ may be divided into, for example, two, three, four, five, or seven or more ranges. Additionally, continuous feedback gain Ka may be made correspond to an angle θ that is not gradual but continuous.

Specific examples when the angle θ of the second arm 13 is divided into nine ranges are shown below. In addition, a case where the operation range of the second arm 13 is 20° to 270° will be described here.

First, when the angle θ is equal to or larger than 20° and smaller than 40° , the feedback gain Ka is preferably from 0.15 to 0.3.

Additionally, when the angle θ is equal to or larger than 40° and smaller than 60° , the feedback gain Ka is preferably from 0.3 to 0.4.

Additionally, when the angle θ is equal to or larger than 60° and smaller than 120° , the feedback gain Ka is preferably from 0.4 to 0.7.

Additionally, when the angle θ is equal to or larger than 120° and smaller than 140° , the feedback gain Ka is preferably from 0.3 to 0.4.

Additionally, when the angle θ is equal to or larger than 140° and smaller than 160° , the feedback gain Ka is preferably from 0.15 to 0.3.

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Additionally, when the angle θ is equal to or larger than 160° and smaller than 200° , the feedback gain K_a is preferably from 0.05 to 0.15.

Additionally, when the angle θ is equal to or larger than 200° and smaller than 220° , the feedback gain K_a is preferably from 0.15 to 0.3.

Additionally, when the angle θ is equal to or larger than 220° and smaller than 240° , the feedback gain K_a is preferably from 0.3 to 0.4.

Additionally, when the angle θ is equal to or larger than 240° and smaller than 270° , the feedback gain K_a is preferably from 0.4 to 0.7.

Fourth Embodiment

The fourth embodiment will be described below mainly regarding differences from the aforementioned third embodiment, and the description of the same matters will be omitted.

In the robot **1** of a fourth embodiment, the second drive source controller **202** adjusts the feedback gain K_a on the basis of tip load mass in the tip portion of the robot **1**, that is, the tip portion of the wrist **16**, in the feedback control.

This tip load mass is the total mass of the manipulator mounted on the wrist **16** and an object to be gripped by the manipulator. That is, the tip load mass is the total mass of the manipulator and the object gripped by the manipulator when the manipulator is gripping the object and is the mass of the manipulator when the manipulator is not gripping the object.

In the present embodiment, both the mass of the manipulator and the mass of the object gripped by the manipulator are already known, and the masses are stored in advance in a storage (not shown) of the control device **20**. Additionally, the control device **20** grasps whether or not the manipulator is gripping the object. Accordingly, the control device **20** always grasps the tip load mass of the robot **1**. In addition, the object to be gripped by the manipulator may be a plurality of kinds of objects having different masses.

Additionally, the second drive source controller **202** sets the feedback gain K_a to be larger as the tip load mass becomes larger.

This is because, as the tip load mass is larger, the control of the robot **1** is stable, but the inertia moment of the second arm **13** around the rotation axis **O1** is large and vibration is large. Thus, the effect of suppressing vibration can be enhanced by setting the feedback gain K_a to be large.

In other words, as the tip load mass is smaller, the inertia moment of the second arm **13** around the rotation axis **O1** is smaller and the vibration in the robot **1** is smaller but control is unstable and vibration occurs easily. Thus, by setting the feedback gain K_a to be small, the vibration in the robot **1** can be prevented, and control can be stabilized.

Next, adjustment of the feedback gain K_a will be described.

In addition, a case where the operation range of the second arm **13** is 50° to 310° will be described here. Additionally, cases where the feedback gains K_a are set in combinations of each of a case where the angle θ of the second arm **13** is smaller than θ_{11} , a case where the angle is equal to or larger than θ_{11} and smaller than θ_{12} , and a case where the angle is equal to or larger than θ_{12} ($\theta_{11} < \theta_{12}$) when the angle θ of the second arm **13** is equal to or larger than 50° and smaller than 180° and each of a case where the tip load mass is 1 kg, a case where the tip load mass is 3 kg, and a case where the tip load mass is 5 kg will be representatively described here, respectively.

Similarly, cases where the feedback gains K_a are set in combinations of each of a case where the angle θ of the

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second arm **13** is smaller than θ_{21} , a case where the angle is equal to or larger than θ_{21} and smaller than θ_{22} , and a case where the angle is equal to or larger than θ_{22} ($\theta_{21} < \theta_{22}$) when the angle θ of the second arm **13** is equal to or larger than 180° and smaller than 310° and each of a case where the tip load mass is 1 kg, a case where the tip load mass is 3 kg, and a case where the tip load mass is 5 kg will be described here, respectively.

First, when the angle θ is equal to or larger than 50° and smaller than θ_{11} and the tip load mass is 1 kg, the feedback gain K_a is preferably from 0.25 to 0.4.

Additionally, when the angle θ is equal to or larger than 50° and smaller than θ_{11} and the tip load mass is 3 kg, the feedback gain K_a is preferably from 0.35 to 0.5.

Additionally, when the angle θ is equal to or larger than 50° and smaller than θ_{11} and the tip load mass is 5 kg, the feedback gain K_a is preferably from 0.4 to 0.7.

Additionally, when the angle θ is equal to or larger than θ_{11} and smaller than θ_{12} and the tip load mass is 1 kg, the feedback gain K_a is preferably from 0.1 to 0.25.

Additionally, when the angle θ is equal to or larger than θ_{11} and smaller than θ_{12} and the tip load mass is 3 kg, the feedback gain K_a is preferably from 0.2 to 0.4.

Additionally, when the angle θ is equal to or larger than θ_{11} and smaller than θ_{12} and the tip load mass is 5 kg, the feedback gain K_a is preferably from 0.3 to 0.6.

Additionally, when the angle θ is equal to or larger than θ_{12} and the tip load mass is 1 kg, the feedback gain K_a is preferably from 0.05 to 0.15.

Additionally, when the angle θ is equal to or larger than θ_{12} and the tip load mass is 3 kg, the feedback gain K_a is preferably from 0.1 to 0.2.

Additionally, when the angle θ is equal to or larger than θ_{12} and the tip load mass is 5 kg, the feedback gain K_a is preferably from 0.25 to 0.4.

Additionally, when the angle θ is smaller than θ_{21} and the tip load mass is 1 kg, the feedback gain K_a is preferably from 0.05 to 0.15.

Additionally, when the angle θ is smaller than θ_{21} and the tip load mass is 3 kg, the feedback gain K_a is preferably from 0.1 to 0.2.

Additionally, when the angle θ is smaller than θ_{21} and the tip load mass is 5 kg, the feedback gain K_a is preferably from 0.25 to 0.4.

Additionally, when the angle θ is equal to or larger than θ_{21} and smaller than θ_{22} and the tip load mass is 1 kg, the feedback gain K_a is preferably from 0.1 to 0.25.

Additionally, when the angle θ is equal to or larger than θ_{21} and smaller than θ_{22} and the tip load mass is 3 kg, the feedback gain K_a is preferably from 0.2 to 0.4.

Additionally, when the angle θ is equal to or larger than θ_{21} and smaller than θ_{22} and the tip load mass is 5 kg, the feedback gain K_a is preferably from 0.3 to 0.6.

Additionally, when the angle θ is equal to or larger than θ_{22} and smaller than 310° and the tip load mass is 1 kg, the feedback gain K_a is preferably from 0.25 to 0.4.

Additionally, when the angle θ is equal to or larger than θ_{22} and smaller than 310° and the tip load mass is 3 kg, the feedback gain K_a is preferably from 0.35 to 0.5.

Additionally, when the angle θ is equal to or larger than θ_{22} and smaller than 310° and the tip load mass is 5 kg, the feedback gain K_a is preferably from 0.4 to 0.7.

Accordingly, the vibration in the robot can be more reliably suppressed while stabilizing control.

According to the robot **1**, the same effects as the aforementioned third embodiment are obtained.

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In the robot 1, by adjusting the feedback gain K_a according to the posture of the second arm 13 and the tip load mass, vibration can be more reliably suppressed while stabilizing control.

In addition, the fourth embodiment can also be applied to a fifth embodiment to be described below.

Fifth Embodiment

FIG. 16 is a schematic view showing a fifth embodiment of the robot of the invention. FIG. 17 is a block diagram of main portions of the robot shown in FIG. 16.

In addition, in the following, for the convenience of description, the upper side in FIG. 16 is referred to as "upper" and "upside" and the lower side is referred to as "lower" and "downside". Additionally, the base side in FIG. 16 is referred to as a "base end", and the opposite side is referred to as a "tip". Additionally, the rotation axes O2 and O3 are shown in an exaggerated manner in FIG. 16, respectively. Additionally, inertia sensors 31, 32b, and 33 are shown outside arms 12, 13, 14 in FIG. 16, respectively, in order to clarify the presence of the sensors.

The fifth embodiment will be described below mainly regarding differences from the aforementioned third embodiment, and the description of the same matters will be omitted.

As shown in FIG. 16, in the robot 1 of the fifth embodiment, the third inertia sensor 33 is installed at the third arm 14. The third inertia sensor 33 detects the angular velocity of the third arm 14 around the rotation axis O2. Although the installation position of the third inertia sensor 33 at the third arm 14 is not particularly limited, a tip portion of the third arm 14 is preferable. In the present embodiment, the third inertia sensor 33 is installed at the tip portion inside the third arm 14. Since the vibration in the third arm 14 becomes the maximum at the tip portion of the third arm, this can more reliably suppress the vibration in the robot 1. In addition, it is obvious that the third inertia sensor 33 may be installed at a base end portion of the third arm 14.

Additionally, the third inertia sensor 33 is not particularly limited, and in the present embodiment, for example, a gyroscope sensor or the like can be used.

In the robot 1, in order to suppress the vibration in the first arm 12, the second arm 13, and the third arm 14, the first inertia sensor 31, the second (b) inertia sensor 32b, and the third inertia sensor 33 are installed at all the first arm 12, the second arm 13, and the third arm 14 as mentioned above, and the operation of the first drive source 401, the second drive source 402, and the third drive source 403 is controlled on the basis of detection results of the first inertia sensor 31, the second (b) inertia sensor 32b, and the third inertia sensor 33. Accordingly, the vibration in the first arm 12, the second arm 13, and the third arm 14 can be reliably suppressed, and thereby, the vibration in the whole robot 1 can be reliably suppressed.

Additionally, in the robot 1, the third drive source controller 203 of the control device 20 is different from that of the third embodiment.

As shown in FIG. 17, the second drive source controller 202 has a subtractor 519, a position controller 529, a subtractor 539, an angular velocity controller 549, a rotation angle calculator 559, an angular velocity calculator 569, a subtractor 579, a converter 589, a correction value calculator 599, and an adder 609.

Additionally, as shown in FIG. 17, the third drive source controller 203 has a subtractor 5110, a position controller 5210, a subtractor 5310, an angular velocity controller 5410, a rotation angle calculator 5510, an angular velocity calcu-

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tor 5610, an adder-subtractor 6110, a converter 5810, a correction value calculator 5910, and an adder 6010. The third drive source controller 203 will be described below.

As shown in FIG. 17, in addition to a position command P_c of the third drive source 403, detection signals are input from the third angle sensor 413, the second (b) inertia sensor 32b, and the third inertia sensor 33, respectively, to the third drive source controller 203. The third drive source controller 203 drives the third drive source 403 by a feedback control using the respective detection signals so that a rotation angle (position feedback value P_{fb}) of the third drive source 403 calculated from the detection signal of the third angle sensor 413 becomes the position command P_c and an angular velocity feedback value ω_{fb} to be described below becomes an angular velocity command ω_c to be described below.

That is, the position command P_c is input to the subtractor 5110 of the third drive source controller 203, and the position feedback value P_{fb} to be described below is input from the rotation angle calculator 5510. In the rotation angle calculator 5510, the number of pulses input from the third angle sensor 413 is counted, and the rotation angle of the third drive source 403 according to the counted value is output to the subtractor 5110 as the position feedback value P_{fb} . The subtractor 5110 outputs a deviation (value obtained by subtracting the position feedback value P_{fb} from a targeted value of the rotation angle of the third drive source 403) between the position command P_c and the position feedback value P_{fb} to the position controller 5210.

The position controller 5210 performs predetermined calculation processing using the deviation input from the subtractor 5110, a proportional gain that is a predetermined factor, and the like and calculates the targeted value of the angular velocity of the third drive source 403 according to the deviation. The position controller 5210 outputs a signal showing the targeted value (command value) of the angular velocity of the third drive source 403 to the subtractor 5310 as the angular velocity command (third angular velocity command) ω_c . In addition, in the present embodiment, a proportional control (P control) is performed as the feedback control. However, the feedback control is not limited to this.

The angular velocity command ω_c and the angular velocity feedback value ω_{fb} to be described below are input to the subtractor 5310. The subtractor 5310 outputs a deviation (value obtained by subtracting the angular velocity feedback value ω_{fb} from the targeted value of the angular velocity of the third drive source 403) between the angular velocity command ω_c and the angular velocity feedback value ω_{fb} to the angular velocity controller 5410.

The angular velocity controller 5410 performs predetermined calculation processing including integration, using the deviation input from the subtractor 5310, a proportional gain that is a predetermined factor, an integration gain, or the like, thereby generating a driving signal (driving current) of the third drive source 403 according to the deviation and supplying the driving signal to the motor of the third drive source 403 via the motor driver 303. In addition, in the present embodiment, the PI control is performed as the feedback control. However, the feedback control is not limited to this.

In this way, the feedback control is performed and the driving current of the third drive source 403 is controlled so that the position feedback value P_{fb} is as equal to the position command P_c as possible and the angular velocity feedback value ω_{fb} is as equal to the angular velocity command ω_c as possible. In addition, since the rotation axis O3 is orthogonal to the rotation axis O1, the rotation axis O3 is not influenced by the operation or vibration of the first arm 12, and the

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operation of the third drive source **403** can be controlled independently from the first drive source **401**.

Next, the angular velocity feedback value ω_{fb} in the third drive source controller **203** will be described.

In the angular velocity calculator **5610**, an angular velocity ω_{m3} of the third drive source **403** is calculated on the basis of the frequency of a pulse signal input from the third angle sensor **413**, and the angular velocity ω_{m3} is output to the adder **6010**.

Additionally, in the angular velocity calculator **5610**, an angular velocity ω_{A3m} of the third arm **14** around the rotation axis **O3** is calculated on the basis of the frequency of the pulse signal input from the third angle sensor **413**, and the angular velocity ω_{A3m} is output to the adder-subtractor **6110**. In addition, the angular velocity ω_{A3m} is a value obtained by dividing the angular velocity ω_{m3} by a reduction ratio between the motor **403M** of the third drive source **403** and the third arm **14**, that is, in the joint **173**.

Additionally, the angular velocity of the third arm **14** around the rotation axis **O2** is detected by the third inertia sensor **33**. A detection signal of the third inertia sensor **33**, that is, an angular velocity ω_{A3} of the third arm **14** around the rotation axis **O2** detected by the third inertia sensor **33** is output to the adder-subtractor **6110**. In addition, since the rotation axes **O2** and **O3** are orthogonal to the rotation axis **O1**, respectively, the angular velocity of the third arm **14** around the rotation axis **O2** can be easily and reliably obtained without being influenced by the operation or vibration of the first arm **12**.

Additionally, the detection signal of the aforementioned second (b) inertia sensor **32b**, that is, the angular velocity ω_{A2} of the second arm **13** around the rotation axis **O2** detected by the second (b) inertia sensor **32b** is output to the adder-subtractor **6110**.

The angular velocity ω_{A3} , the angular velocity ω_{A2} , and the angular velocity ω_{A3m} are input to the adder-subtractor **6110**, and the adder-subtractor **6110** outputs a value ω_{A3s} ($=\omega_{A3}-\omega_{A2}-\omega_{A3m}$) obtained by subtracting the angular velocity ω_{A2} and the angular velocity ω_{A3m} from the angular velocity ω_{A3} to the converter **5810**. The value ω_{A3s} is equivalent to a vibration component (vibration angular velocity) of the angular velocity of the third arm **14** around the rotation axis **O3**. Hereinafter, ω_{A3s} is referred to as a vibration angular velocity. In the present embodiment, a feedback control is performed in which the vibration angular velocity ω_{A3s} (in detail, an angular velocity ω_{m3s} in the motor **403M** that is a value generated on the basis of the vibration angular velocity ω_{A3s}) is multiplied by a gain K_a to be described below and is returned to the input side of the third drive source **403**. Specifically, a feedback control is performed on the third drive source **403** so that the vibration angular velocity ω_{A3s} becomes as close to 0 as possible. Accordingly, the vibration in the robot **1** can be suppressed. In addition, the angular velocity of the third drive source **403** is controlled in the feedback control.

The converter **5810** converts the vibration angular velocity ω_{A3s} into the angular velocity ω_{m3s} in the third drive source **403**, and outputs the angular velocity ω_{m3s} to the correction value calculator **5910**. This conversion can be obtained by multiplying the vibration angular velocity ω_{A3s} by the reduction ratio between the motor **403M** of the third drive source **403** and the third arm **14**, that is, in the joint **173**.

The correction value calculator **5910** multiplies the angular velocity ω_{m3s} by a gain (feedback gain) K_a that is a predetermined factor, obtains a correction value (third correction component) $K_a \cdot \omega_{m3s}$, and outputs the correction value $K_a \cdot \omega_{m3s}$ to the adder **6010**. In addition, the gain K_a in the

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third drive source controller **203**, the gain K_a in the first drive source controller **201**, and the gain K_a in the second drive source controller **202** may be the same or may be different, respectively.

The angular velocity ω_{m3} and the correction value $K_a \cdot \omega_{m3s}$ are input to the adder **6010**. The adder **6010** outputs an additional value of the angular velocity ω_{m3} and the correction value $K_a \cdot \omega_{m3s}$ to the subtractor **5310** as the angular velocity feedback value ω_{fb} . In addition, the subsequent operation is the same as that of the third embodiment.

According to the robot **1**, the same effects as the aforementioned first embodiment are obtained.

In the robot **1**, since the control of suppressing vibration is also performed on the third arm **14**, the vibration in the robot **1** can be more reliably suppressed.

Although the above robot of the invention has been described on the basis of the illustrated embodiments, the invention is not limited to this, and the configurations of the respective portions can be replaced with arbitrary configurations having the same functions. Additionally, other arbitrary structures may be added to the invention.

Additionally, the invention may be provided from the combination of two or more arbitrary configurations (features) among the respective embodiments.

In addition, the respective motors include, for example, stepping motors or the like in addition to the servo motors, respectively.

Additionally, in the above embodiments, the encoders are used as the respective angle sensors, respectively. However, the invention is not limited to these. For example, other various sensors, such as resolvers or potentiometers, which detect the rotation angles of rotor of the motors, may be used, and various sensors, such as tachogenerators, which detect the rotating speed of the rotors of the motors, may be used. In addition, when the stepping motors are used as the motor, the rotation angle or rotating speed of the rotors of the motors may be detected, for example, by measuring the number of driving pulses input to the stepping motors.

Additionally, in the above embodiments, the gyroscope sensors are used as the respective inertia sensors, respectively. However, the invention is not limited to these. For example, other various angular velocity sensors that detect the angular velocity of the arms may be used, and various acceleration sensors that detect the acceleration of the arms may be used. In addition, when the acceleration sensors are used, angular velocity is calculated using the detection values of the acceleration sensors.

Additionally, the types of the respective angle sensors and the respective inertia sensors are not particularly limited, and include, for example, an optical type, a magnetic type, an electromagnetic type, an electric type, or the like.

Additionally, in the above embodiments, the number of rotation axes of the robot is six. However, the invention is not limited to this, and the number of rotation axes of the robot may be two, three, four, five, or seven or more.

That is, in the above embodiments, the number of arms of the robot is six because the wrist has two arms. However, the invention is not limited to this, and the number of arms of the robot may be two, three, four, five, or seven or more.

Additionally, in the above embodiments, the robot is a single arm robot that has one arm coupling body obtained by rotatably coupling a plurality of arms. However, the invention is not limited to this. For example, as shown in FIG. **18**, robots having a plurality of the arm coupling bodies, such as a double-arm robot **1A** having the two arm coupling bodies **18** each obtained by rotatably coupling a plurality of arms, may be used.

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Additionally, in the above embodiments, the manipulator is detachably mounted on the wrist as the functional portion. However, the invention is not limited to this, and the functional portion (end effector) includes a drill, a welder, a laser irradiation machine, or the like in addition to this manipulator.

Additionally, in the above embodiments, those including the angle detection unit that detects the angle θ formed between the axis of the first present arm and the axis of the second arm or the angle detection unit that detects the angle θ between the axis of the second present arm and the axis of the third arm is used as the posture detection unit. However, the invention is not limited to this. Besides, the posture detection unit includes a unit that acquires the targeted values (command values) of the rotation angle of the drive sources. The posture detection unit, for example, obtains an angle θ in the following control cycle on the basis of the targeted value of the rotation angle of a drive source in the following control cycle and the current angle θ . In this case, the feedback gain K_a is set to a predetermined value on the basis of the angle θ in the following control cycle.

Additionally, for example, the feedback gain K_a may be adjusted on the basis of the current position of a tip portion of an arm, the command value of the position of the tip portion of the arm in the following control cycle, the current position of the tip portion of the wrist of the robot that is an arm closest to the tip side, the command value of the position of the tip portion of the wrist in the following control cycle, or the like.

The entire disclosure of Japanese Patent Application No. 2012-191451 filed Aug. 31, 2012 is expressly incorporated by reference herein.

What is claimed is:

1. A robot comprising:

a base;

a first arm that is coupled to the base and rotates with a first rotation axis as an axial center;

a second arm that is coupled to the first arm and rotates with a second rotation axis in a direction different from the first rotation axis as an axial center;

a third arm that rotates with a third rotation axis in a direction parallel to the second rotation axis as an axial center;

a first drive source that rotates the first arm through a first angular velocity command;

a first inertia sensor that is installed at the first arm and detects a first angular velocity or acceleration of the first rotation axis of the first arm;

a first angle sensor that detects a rotation angle of the first drive source;

a second drive source that rotates the second arm through a second angular velocity command;

a second angle sensor that detects a rotation angle of the second drive source;

a third drive source that rotates the third arm through a third angular velocity command;

a second inertia sensor that is installed at the third arm and detects a second angular velocity or acceleration of the second rotation axis of the third arm;

a third angle sensor that detects a rotation angle of the third drive source;

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a posture detection unit that detects a posture of the third arm with the second arm as a reference and derives a feedback gain;

a first drive source control unit that feeds back a first correction component that is derived from the first angular velocity of the first rotation axis of the first arm obtained from the first inertia sensor and a third angular velocity of the first rotation axis of the first arm based on the rotation angle from the first angle sensor, and controls the first drive source; and

a second drive source control unit that feeds back a second correction component that is obtained by multiplying a vibration component value by the feedback gain, and controls the second drive source, wherein the vibration component value is derived from the second angular velocity, a fourth angular velocity of the second rotation axis of the second arm, and a fifth angular velocity of the third rotation axis of the third arm, wherein the fourth angular velocity is based on the rotation angle from the second angle sensor and the fifth angular velocity is based on the rotation angle from the third angle sensor.

2. The robot according to claim 1, wherein:

the first correction component is obtained by multiplying a value, which is obtained by subtracting the third angular velocity from the first angular velocity, or a value derived from the obtained value, by a feedback gain, and controls the first drive source.

3. The robot according to claim 1, wherein:

the posture detection unit includes the third angle sensor and detects an angle formed between the axis of the second arm and the axis of the third arm.

4. The robot according to claim 1, wherein:

the posture detection unit detects an angle formed between the axis of the second arm and the axis of the third arm, and increases the feedback gain as the angle approaches 180° .

5. The robot according to claim 1, wherein:

the posture detection unit adjusts the feedback gain, on the basis of the mass of an end effector or the mass of the end effector and an object to be gripped by the end effector.

6. The robot according to claim 1, wherein:

the posture detection unit decreases the feedback gain as the mass becomes larger.

7. The robot according to claim 1, wherein:

the first inertia sensor is installed at a tip portion of the first arm; and

the second inertia sensor is installed at a tip portion of the third arm.

8. The robot according to claim 1, wherein:

the first arm rotates with the first rotation axis that coincides with a normal line of an installation surface of the base, as an axial center.

9. The robot according to claim 1, wherein:

the second arm rotates with the second rotation axis that is orthogonal to the first rotation axis or parallel to an axis orthogonal to the first rotation axis, as an axial center.

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